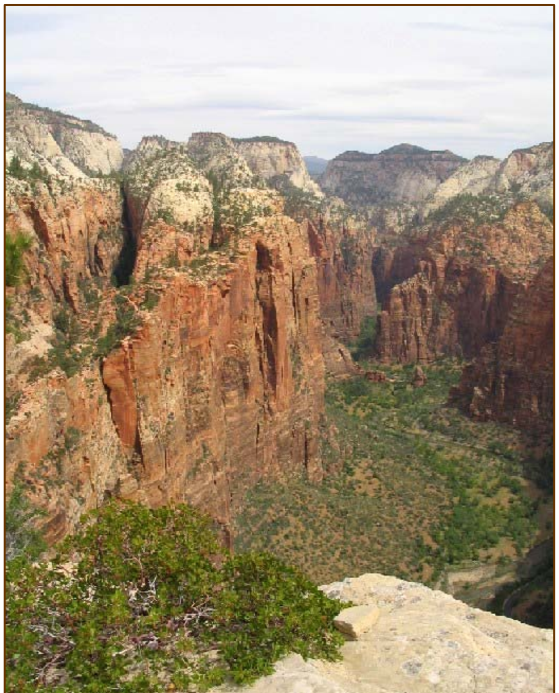
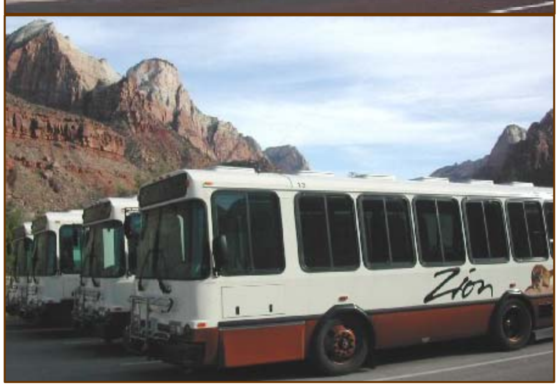
# GREENHOUSE GAS EMISSIONS INVENTORY






# ZION NATIONAL PARK

**Prepared by ICF Consulting**

**On behalf of the**

**Environmental Protection Agency,
National Park Service, and
Zion National Park**

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# EXECUTIVE SUMMARY

This report provides an inventory of greenhouse gas (GHG) emissions associated with activities at Zion National Park. The Zion inventory is the first GHG emissions inventory of a southwestern park and the third GHG inventory ever conducted for a national park.[1] These inventories have been developed in conjunction with a pilot project initiated by the National Park Service (NPS), with assistance from the Environmental Protection Agency (EPA). The pilot project was designed to establish a Climate Friendly Parks Program (CFP) within the NPS Green Parks Partnership Program. The Climate Friendly Parks Program aims to reduce park-related GHG emissions and to inform the public about the climate-friendly actions each park is taking and the reasoning behind the actions.

Zion National Park is located in Southwestern Utah and is characterized by its deep and narrow canyons, striking cliffs, and plateaus. Zion was first established as Mukuntuweap National Monument in 1909; it was expanded and designated a National Park in 1919. Zion spans nearly 147,000 acres (229 square miles) including two major canyons: Zion in the south and Kolob in the northwest (see map in Figure 1.1). The southern area of the park is lower in elevation consisting of desert areas with mesas and red-rock canyons, while higher forest-covered plateaus characterize the northern areas of the park. Park elevations range from about 3,670 to 8,730 feet above sea level (NPS 2004).

The purpose of this inventory is to provide the foundation for discussions of GHG emissions at Zion and to assist park officials in identifying ways to reduce these emissions. In addition, the inventory will provide Zion with a baseline against which future actions to reduce emissions may be compared.

This national park inventory includes estimates of GHG emissions from activities attributable to park operations (e.g., stationary combustion, mobile combustion) as well as GHG removals by sinks (e.g., forests). Once emissions and sinks are measured, the park may consider options to reduce emissions. In the interest of considering a full range of options for reducing emissions, the GHG inventory for Zion also includes "indirect emissions," or emissions from sources that are not directly within the park's control, but which the park has some influence over (e.g., purchased electricity, visitor vehicle emissions, concessionaire operations, waste management). Consideration of these indirect emissions will both expand the park's portfolio of possible emissions reduction actions and enable the park to work with its electricity providers, waste haulers, concessionaires, and visitors to reduce park-related emissions occurring outside park boundaries.

This inventory provides an overview of emissions at Zion in 2002. Because the principle goal of inventories developed as part of the Climate Friendly Parks Program is to provide the parks with a foundation for identifying and implementing activities to reduce emissions, the park inventories may not reflect all sources of emissions. The Zion inventory includes the most significant sources of emissions at the park, but does not include a couple of minor sources due to data and resource limitations. Criteria used to decide which sources to include are described below. Because data availability, contractor resources, and park staff time are inconsistent across parks, some park inventories are more comprehensive than others. Specific sources that have been excluded from this inventory include refrigeration and air conditioning, solvent use, agriculture, and wastewater. Readers should refer to Table 1.2 for a more detailed explanation of emission sources included and excluded in the Zion Inventory.

[1] A few southwestern parks have included $CO_2$ in their air emissions analyses; however, the only other inventories of GHG emissions (i.e., including $CO_2$ and non-$CO_2$ GHGs) at national parks were conducted for Gateway National Recreation Area (ICF 2003) and Glacier National Park (ICF 2004).

The sources included in this GHG inventory were chosen based on (1) whether emissions are reasonably attributable to park activities; (2) whether opportunities exist for reducing emissions from the activity; (3) whether emissions from each source were significant enough to warrant substantial data collection and emission estimation efforts; and (4) whether data were available for collection. The GHG sources reported in this inventory include:

- Carbon dioxide, methane, and nitrous oxide from stationary combustion
  - direct combustion
  - purchased electricity (indirect)
- Carbon dioxide, methane, and nitrous oxide from mobile combustion
  - highway vehicles
  - nonroad vehicles
- Methane from waste disposal
- Carbon dioxide flux from forests
- Methane and nitrous oxide from burning

In addition to estimating emissions by source, emissions from each source were broken down into park-owned and leased, residence, concessionaire, and visitor activities. The remainder of this executive summary provides an overview of emissions for Zion, provides some analysis of the key sources of emissions, and compares Zion's emissions with those at Gateway National Recreation Area and Glacier National Park—the only other parks with GHG inventories.

## ES.1 OVERALL GREENHOUSE GAS EMISSIONS AND SINKS

Naturally occurring GHGs include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), water vapor, and ozone ($O_3$). Human activities (e.g., fuel combustion in stationary and mobile sources, and waste disposal) lead to increased concentrations of these gases in the atmosphere. In addition, there are other more powerful GHGs—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$)—called high-global warming potential (high-GWP) gases that are created by various industrial processes. Global warming potentials are assigned to various GHGs to weight their ability to trap heat in the atmosphere. This ability is measured relative to the most commonly occurring GHG: $CO_2$, which has a GWP of 1. GHGs inventoried for Zion included $CO_2$, $CH_4$, and $N_2O$. In order to compare emissions of these gases with different heat trapping abilities, the GWPs for each gas were used to express emissions for Zion in metric tons of carbon equivalent (MTCE).[2]

GHG emissions for Zion were estimated for stationary combustion (i.e., burning of fuel for heating, cooling, and cooking in buildings and campfires), mobile combustion (i.e., highway and nonroad vehicle use within the park), landfilled waste (i.e., waste generated in the park but disposed at area landfills), and burning and thinning of forests. Carbon flux in Zion's forests (i.e., the difference between the amount of carbon that is sequestered from the atmosphere and stored in the forests and the amount that is emitted through forest decay, thinning, and burning) was also estimated for Zion. The results of this analysis showed that Zion's forests stored more carbon than they released in 2002, thus making the forests a net sink.

The body of the report separates Zion's overall emissions into four categories: park-owned and leased operations, residence, concessionaire, and visitor activities. Note that the National Park Service and its concessionaires are responsible for paying for electricity used by visitors in park buildings and concessionaire facilities. Similarly, the National Park Service and park concessionaires are responsible for managing visitor-generated wastes. For these reasons, visitor emissions from stationary combustion and waste disposal were unable to be quantified separately. Instead, electricity consumption and waste generation attributable to Zion's visitors are reflected in the estimates for the park or the concessionaires that provide those services.

GHG results are presented here in three ways: (1) overall for both emissions and sinks; (2) for gross emissions only; and (3) for sinks only (i.e., the carbon flux in Zion's forests). The reason for evaluating carbon flux separately is because this inventory's aim is to focus on GHGs emitted to the atmosphere from activities within the park that present opportunities for GHG reduction. For example, Zion has control over the type and quantity of its fuel, its vehicle fleet and miles traveled, and the quantity of waste landfilled or recycled. Because the CFP program is focused on helping parks reduce emissions, carbon flux was treated as a separate, but important, component of the Zion inventory. In addition, a great deal of uncertainty is inherent in the forest carbon flux estimates.

Based on the results of this analysis, Zion emitted approximately 2,840 metric tons of carbon equivalent (MTCE) in 2002; when accounting for carbon sequestered in new forestry growth, Zion's net emissions were 160 MTCE. Table ES.1 presents overall emissions and sinks by source and gas for Zion. Although Zion emitted about 2,024 MTCE of $CO_2$ from stationary and mobile combustion (506 and 1,518, respectively) in 2002, the sequestering of 2,679 MTCE by the forests offset these emissions and resulted in overall $CO_2$ sequestration of about 654 MTCE. Overall $CH_4$ and $N_2O$ emissions were 667 and 147 MTCE, respectively. Burning accounted for the majority of these non-$CO_2$ emissions—65 percent of $CH_4$ and 68 percent of $N_2O$. The next largest source of $CH_4$ was landfilled waste (33 percent), while mobile combustion contributed to 31 percent of overall $N_2O$ emissions.

**Table ES.1: Overall GHG Emissions and Sinks**

| Source | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Stationary Combustion** | **506.4** | **8.5** | **2.4** | **517.2** |
| Direct Combustion | 305.0 | 8.5 | 2.4 | 315.9 |
| Indirect – Purchased Electricity | 201.3 | NE | NE | 201.3 |
| **Mobile Combustion** | **1,518.2** | **3.7** | **45.2** | **1,567.1** |
| Highway Vehicles | 1,508.6 | 3.7 | 45.1 | 1,557.4 |
| Nonroad Vehicles/Equipment | 9.6 | + | 0.1 | 9.7 |
| **Landfilled Waste** | **NA** | **220.1** | **NA** | **220.1** |
| **Forestry** | **(2,679.0)** | **435.0** | **99.5** | **(2,144.5)** |
| Forest ($CO_2$ Flux) | (2,679.0) | NA | NA | (2,679.0) |
| Burning ($CH_4$ and $N_2O$ only) | NA | 435.0 | 99.5 | 534.5 |
| **TOTAL GROSS EMISSIONS*** | **2,024.5** | **667.3** | **147.1** | **2,839.0** |
| **TOTAL NET EMISSIONS*** | **(654.4)** | **667.3** | **147.1** | **160.0** |

Note: Totals may not sum due to independent rounding. Parentheses indicate net carbon sequestration.
NE = Not Estimated. NA = Not Applicable. + Does not exceed 0.05 MTCE.
* Gross emissions do not include carbon sequestered in forest sinks. Net emissions reflect the subtraction of carbon sequestration from gross emissions.

[2] Carbon comprises 12/44 of the mass of $CO_2$. To convert from $CO_2$ equivalent to C equivalent, emissions were multiplied by 12/44.

## ES.2 GROSS GREENHOUSE GAS EMISSIONS

Gross GHG emission results for Zion by gas are presented in Table ES.2. Focusing on emission sources only, Zion emitted roughly 2,840 MTCE in 2002. $CO_2$ emissions from fuel combustion in vehicles accounted for the majority of GHG emissions (53 percent), followed by $CH_4$ and $N_2O$ from burning (19 percent), $CO_2$ emissions from direct stationary combustion (11 percent), $CH_4$ emissions from landfilled waste (8 percent), and $CO_2$ emissions from purchased electricity (7 percent).

**Table ES.2: Gross GHG Emissions**

| Source | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Stationary Combustion** | **506.4** | **8.5** | **2.4** | **517.2** |
| Direct Combustion | 305.0 | 8.5 | 2.4 | 315.9 |
| Indirect – Purchased Electricity | 201.3 | NE | NE | 201.3 |
| **Mobile Combustion** | **1,518.2** | **3.7** | **45.2** | **1,567.1** |
| Highway Vehicles | 1,508.6 | 3.7 | 45.1 | 1,557.4 |
| Nonroad Vehicles/Equipment | 9.6 | + | 0.1 | 9.7 |
| **Landfilled Waste** | **NA** | **220.1** | **NA** | **220.1** |
| **Forestry** | **NA** | **435.0** | **99.5** | **534.5** |
| Burning ($CH_4$ and $N_2O$ only) | NA | 435.0 | 99.5 | 534.5 |
| **TOTAL** | **2,024.5** | **667.3** | **147.1** | **2,839.0** |

Note: Totals may not sum due to independent rounding.
NE = Not Estimated. NA = Not Applicable. + Does not exceed 0.05 MTCE.

As shown in Figure ES.1, $CO_2$ accounted for the largest share of gross emissions (71 percent), while $CH_4$ and $N_2O$ accounted for 24 and 5 percent of emissions, respectively. Generally, $CO_2$ comprises an even larger share of emissions in state and national GHG inventories; however, the estimation of $CH_4$ and $N_2O$ from burning—which had the largest impact on gross $CH_4$ and $N_2O$ emissions from the park—has not yet been incorporated into these inventories.

**Figure ES.1: Zion Gross GHG Emissions by Gas**

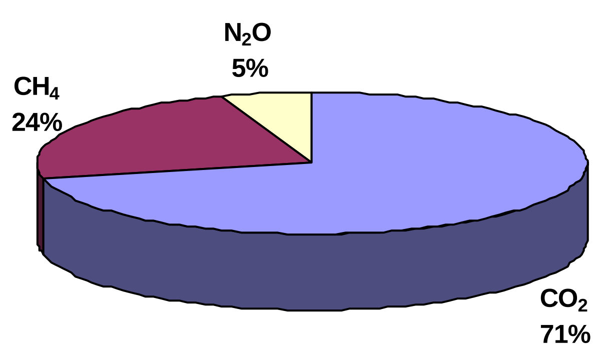
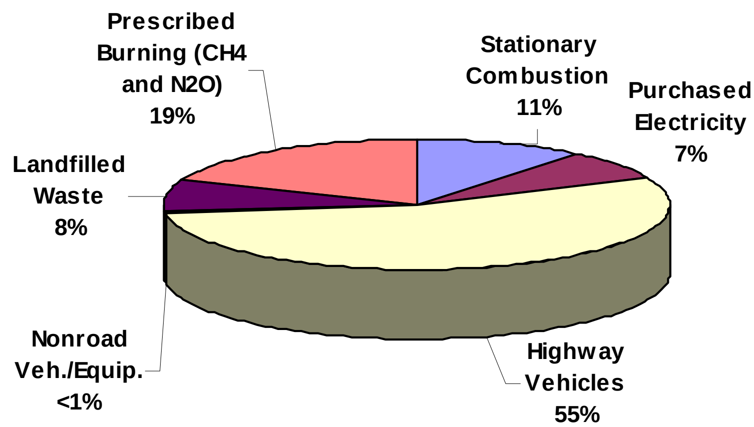



Figure ES.2 presents the breakdown of emissions from each of the key categories listed in Table ES.2: stationary combustion, purchased electricity, highway vehicles, nonroad vehicles/equipment, landfilled waste, and burning ($CH_4$ and $N_2O$ only). Highway vehicles had the largest overall impact on GHG emissions.

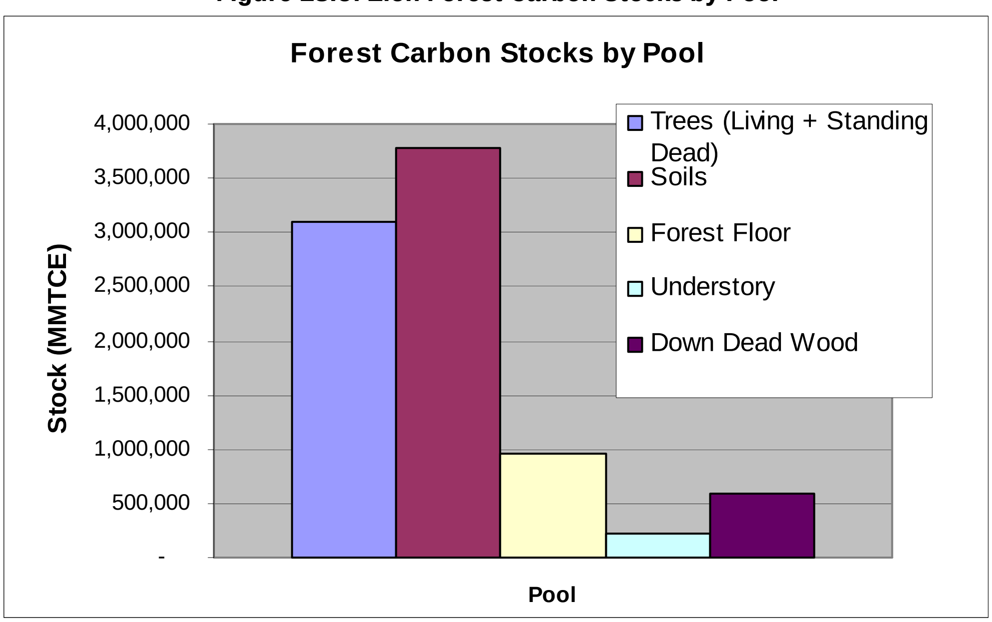
**Figure ES.2: Zion Gross GHG Emissions by Source**




## ES.3 NET $CO_2$ FOREST FLUX

The net $CO_2$ flux from the forests was about -2,680 MTCE in 2002. This indicates that the forests sequestered more carbon through photosynthesis than they emitted through decay, thinning, or burning. Soils and trees were the primary sinks of carbon in Zion's forests. However, $CO_2$ forest flux is highly variable year to year. Factors such as natural/prescribed burns, changes in ecosystem health, and rainfall and other climate variables impact the rate of both sequestration and emissions. In the short term, the current policy of promoting natural, healthy ecosystems through prescribed burns might actually cause net emissions of $CO_2$; in the long term, however, the prescribed burns may reduce $CO_2$ emissions by preventing catastrophic forest fires, which release large quantities of $CO_2$.

**Figure ES.3: Zion Forest Carbon Stocks by Pool**



## ES.4 Significant Sources

Transportation-related activities comprise the majority of emissions at Zion, and there is a wide disparity in emissions associated with park operations (shuttle buses and other park vehicles), leased operations (GSA and Acme vehicles), concessionaire operations (Xanterra vehicles), and visitor activities (vehicles, motor homes, and tour buses). Figure ES.4 below provides an illustration of transportation-related emissions from these categories. As the graph indicates, visitor emissions dominated the emission profile, and in all cases, $CO_2$ accounted for the majority of emissions.

**Figure ES.4: Park-Owned, Leased, Xanterra, and Visitor-Related Transportation Emissions**

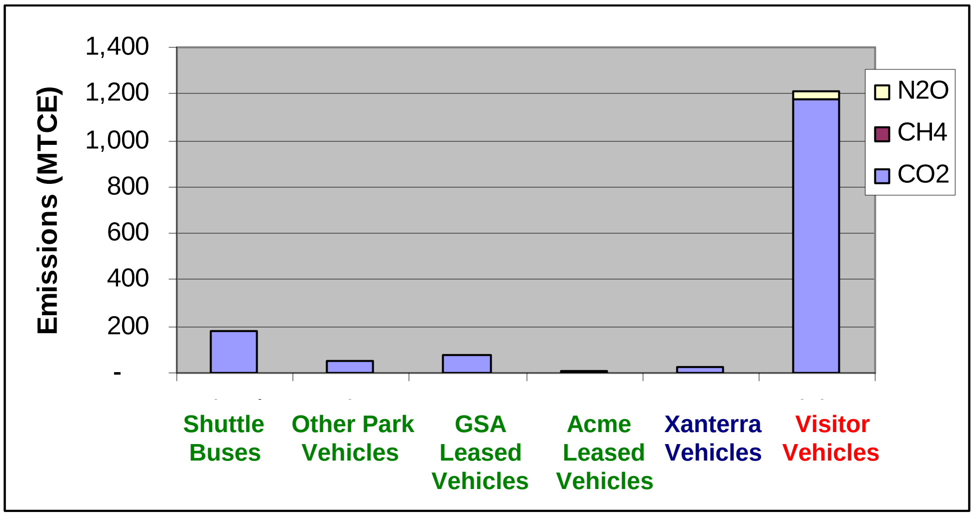



Table ES.3 presents a detailed accounting of transportation emissions at Zion. Emissions are provided by subcategory (highway vehicles and nonroad vehicles) and by ownership class (park-owned, park-leased, concessionaire, visitor). As the columns at the far right demonstrate, highway vehicles account for nearly all of the transportation-related emissions at the park. Visitor highway vehicle use accounts for 77 percent of transportation emissions, followed by park shuttle bus highway emissions of 12 percent and GSA highway emissions of 5 percent. Within the nonroad category, park operations accounted for nearly all (99 percent) emissions.

**Table ES.3 Transportation Emissions**

| Source Category | Emissions (MTCE) $CO_2$ | $CH_4$ | $N_2O$ | Total | % of Transp Total | % of Sub Category Total |
|---|---|---|---|---|---|---|
| **Highway Vehicles** | **1,508.6** | **3.7** | **45.1** | **1,557.4** | **99%** | **100%** |
| Park-Owned Operations | 227.8 | 0.3 | 5.5 | **233.5** | 15% | 15% |
| *Shuttle Buses* | *176.2* | *0.2* | *4.4* | ***180.9*** | *12%* | *12%* |
| *Other Park Vehicles* | *51.5* | *0.1* | *1.0* | ***52.6*** | *3%* | *3%* |
| Park-Leased Operations | 85.2 | 0.2 | 2.4 | **87.7** | 6% | 6% |
| *GSA* | *76.2* | *0.2* | *2.1* | ***78.4*** | *5%* | *5%* |
| *Acme* | *9.0* | *+* | *0.2* | ***9.3*** | *1%* | *1%* |
| Xanterra Operations | 23.1 | 0.1 | 0.7 | **23.9** | 2% | 2% |
| Visitors | 1,172.5 | 3.2 | 36.6 | **1,212.2** | 77% | 78% |
| **Nonroad Vehicles/Equipment** | **9.6** | **+** | **0.1** | **9.7** | **1%** | **100%** |
| Park-Owned Operations | 9.5 | + | 0.1 | **9.6** | 1% | 99% |
| Park-Leased Operations | NA | NA | NA | **+** | <1% | <1% |
| Xanterra Operations | 0.1 | + | + | **0.1** | <1% | 1% |
| Visitors | NA | NA | NA | **+** | <1% | <1% |
| **TOTAL EMISSIONS** | **1,518.2** | **3.7** | **45.2** | **1,567.1** | **100%** | **NA** |

Note: Totals may not sum due to independent rounding.
NA = Not Applicable. IE = Included Elsewhere. + Does not exceed 0.05 MTCE.

## ES.5 EMISSIONS IN CONTEXT

Because Zion is the third park to participate in the CFP program, the park's GHG emissions inventory results can be considered in the context of the other two GHG emissions inventories. The other parks for which EPA has inventoried $CO_2$, $CH_4$, and $N_2O$ emissions are Gateway National Recreation Area and Glacier National Park. All three parks are located in different regions of the United States with varying geography and climate and offer distinctly different attractions to visitors. Gateway is an urban park, founded in 1972, and located in the New York metropolitan area and in northern New Jersey. The park extends across 26,000 acres of land and water, including former military fortifications, one of the largest bird sanctuaries in the northeastern United States, and several miles of beaches. More than 10 million visitors come to Gateway each year. In comparison, Glacier was founded in 1910, is located in northwestern Montana, and spans more than one million acres including more than 500,000 acres of forest. Despite its large area, Glacier receives much fewer visitors—approximately 1.9 million people each year. Zion, designated a national park in 1919, is located in southwestern Utah and covers nearly 147,000 acres, consisting of canyons and plateaus. The park welcomes approximately 2.5 million visitors each year.

When the emissions for these three parks are compared, Zion stands out; this park emitted significantly less GHGs than the other two parks. Gateway and Glacier surprisingly had very similar emission profiles despite the differences in environment, scale, location, and visitorship of the two parks. Table ES.5 (at the end of this section) provides a comparison of gross and net emissions in MTCE by source for each of the parks.[3]

[3] Readers should note that, while the per visitor estimates of GHG emissions can help put individual parks in context, park emissions are not actually perfectly comparable to each other. Based on the source selection criteria described earlier in this report, each park inventory accounted for slightly different sources. Gateway's inventory included emissions from wastewater, refrigeration, and air conditioning, which were not included in other park inventories. It is also important to note that Gateway's inventory did not

Zion's gross emissions in 2002 were much lower than Gateway's and Glacier's, primarily due to:

- *Fuel use*: Zion consumed 71 percent less fuel than Glacier—27 percent less in buildings for heating, cooling, and cooking; and 74 percent less in vehicles.
- *Electricity purchases*: Zion purchased 74 percent less electricity than Glacier and 86 percent less than Gateway for park operations.
- *Purchased electricity fuel mix*: The electricity purchased by Zion contained the highest content of renewable energy (60 percent) as compared to 53 and 2 percent on average,[4] in the electricity purchased by Glacier and Gateway, respectively.
- *Miles traveled*: Park-owned, leased, concessionaire, and visitor vehicles traveled about 10.9 million miles in 2002 at Zion, while vehicles in Glacier traveled about 41.2 million miles and vehicles in Gateway (excluding concessionaires) traveled 35.8 million miles.

The lower number of visitors and concessionaire operations at Zion (as compared to Gateway) contributed to Zion's lower fuel use, electricity purchases, and miles traveled as compared to the other parks. In addition, Zion has already implemented energy and water conservation projects in the park (e.g., installation of an energy efficient cooling and heating system in Zion's new visitor center) as well as the park's visitor shuttle system (described in more detail below). These efforts also help explain Zion's comparably lower emissions.

Although the three parks' inventories included slightly different sources, there are common trends among the emission results for all three parks. For example, $CO_2$ emissions from fossil fuel combustion accounted for the majority of gross emissions for all parks—93 percent of emissions at Glacier versus 97 percent of emissions at Gateway and 88 percent of emissions at Zion (excluding burning which was not included in the other park inventories). Additionally, in all the parks, visitor vehicle traffic was the single largest source of emissions. Visitor vehicle emissions from Zion, Glacier, and Gateway each accounted for 77, 93, and 95 percent of their respective park's total mobile emissions. The proportion of emissions at Zion attributed to visitor vehicle emissions is slightly lower than that for the other parks because many visitor vehicles have been removed from Zion's roads and replaced with the propane-fueled visitor shuttle, which is required for travel along Zion Canyon Scenic Drive between April and October. Including the shuttle bus estimates in the visitor vehicle total brings Zion's visitor vehicle share of mobile emissions up to 89 percent. Because the total number of miles traveled in each park have a significant impact on the emissions from mobile combustion, Zion emitted far less than the other parks. The miles traveled by visitor vehicles at Zion is about a fourth of that in Glacier and Gateway. Surprisingly, Gateway and Glacier had comparable visitor vehicle emissions because of the combination of high mileage and a low number of visitor vehicles in the case of Glacier and low mileage and a high number of visitor vehicles at Gateway. The greater driving distances per visitor in Glacier also help to explain Glacier's higher emissions per visitor; dividing the parks' total gross GHG emissions by their 2002 visitation shows that Glacier emits about four times more GHGs per visitor than do Zion and Gateway (8.4 pounds per visitor in Glacier versus 2.4 pounds per visitor in Zion and 1.7 pounds per visitor in Gateway). Although each Zion visitor on average emits more pounds per visitor than a Gateway visitor, Zion only receives about 25 percent as many visitors as Gateway.

account for emissions/sinks due to forest flux. Glacier's and Zion's inventories were more comparable; however, Glacier was not able to provide sufficient data to estimate $CH_4$ and $N_2O$ from burning in forests.

[4] Note that Gateway's electricity comes from two eGRID subregions, NPCC NYC/Westchester and MAAC All, because the park covers two states (i.e., New York and New Jersey).

In comparing emission sinks estimated for the two western parks, Zion's carbon flux of about -2,680 MTCE is significantly smaller than that estimated for Glacier (–78,500 MTCE). This is partially because Zion's landscape includes far fewer acres of forest, and the forest types that are present did not grow as rapidly as Glacier's dense forests. Additionally, carbon stocks in Zion's forests were estimated at 8.7 million MTCE versus 45.7 million MTCE at Glacier.

**Table ES.4: Emissions Comparison: Zion vs. Glacier and Gateway**

| Source Category | Total Emissions (MTCE) | | |
|---|---|---|---|
| | **Zion[a]** | **Glacier[b]** | **Gateway** |
| **$CO_2$ from Fossil Fuel Combustion** | **2,024.5** | **6,799.9** | **7,648.1** |
| Direct Combustion | 1,823.2 | 6,303.9 | 5,702.4 |
| *Mobile Combustion* | 1,518.2 | 5,953.8 | 4,073.0 |
| *Stationary Combustion* | 305.0 | 350.0 | 1,629.5 |
| Indirect - Purchased Electricity | 201.3 | 496.0 | 1,945.7 |
| **$CH_4$ and $N_2O$ from Stationary Combustion** | **10.8** | **9.8** | **6.0** |
| **$CH_4$ and $N_2O$ from Mobile Combustion** | **48.9** | **182.5** | **132.0** |
| Highway Vehicles | 48.9 | 182.0 | 130.7 |
| Nonroad Vehicles | 0.1 | 0.5 | 1.3 |
| *Equipment/Nonroad Vehicles* | *0.1* | *0.4* | *0.3* |
| *Boats* | *NA* | *0.1* | *1.1* |
| **Landfilled Waste** | **220.1** | **306.4** | **64.6** |
| **Forestry** | **(2,144.5)** | **(78,526.4)** | **NE** |
| Forest ($CO_2$ Flux) | (2,679.0) | (78,526.4) | NE |
| Burning ($CH_4$ and $N_2O$ only) | 534.5 | NE | NA |
| **TOTAL GROSS EMISSIONS** | **2,839.0** | **7,298.5** | **7,850.7** |
| **TOTAL NET EMISSIONS[c]** | **160.0** | **(71,227.8)** | **7,850.7** |

Note: Totals may not sum due to independent rounding.
NA = Not Applicable. NE = Not Estimated.
[a] Includes emissions from concessionaires and stationary and waste emissions from residences.
[b] Includes emissions from concessionaires.
[c] Includes emissions and sinks.

## ES.6 Possible Actions to Reduce Emissions

Zion's gross emissions account for far less than 1 percent of Utah's overall emissions; however, many opportunities to reduce GHG emissions still exist at Zion. The park and Xanterra can go beyond those initiatives that are already underway at the park and take a number of steps to reduce Zion's $CO_2$, $CH_4$, and $N_2O$ emissions and save money in the long run. Throughout this report, actions to reduce GHGs from stationary, mobile, and waste activities are recommended and, where possible, the savings are described. Table ES.5 presents an overview of possible actions that Zion could take to reduce emissions, increase awareness on climate change, and in many cases, experience long-term cost savings.

**Table ES.5: Possible Actions for Reducing GHG Emissions**

| Category / Action | Benefits |
|---|---|
| **Facilities** | |
| Switch a portion of petroleum usage to natural gas | Reduction in $CO_2$, $CH_4$, and $N_2O$ |
| Purchase a greater share of Blue Sky Wind Power | |
| Reduce overall fuel use | Reduction in $CO_2$, $CH_4$, and $N_2O$ from lowered energy use; Long-term cost savings |
| Install energy-efficient lighting, make use of solar energy in the Southwest | |
| Install energy efficient appliances | |
| Improve building insulation (repair or replace windows); retrofit older buildings (e.g., Admin building, residences) | |
| Install motion sensors | |
| **Transportation**[5] | |
| Use alternative fuels in vehicles in the park, especially in the dual fuel GSA vehicles equipped to use ethanol | Reduction in $CO_2$, $CH_4$, and $N_2O$ |
| Expand visitor shuttle to other sections of the park | |
| Purchase alternative fuel or hybrid vehicles to replace aging park-owned or leased highway vehicles and nonroad vehicles/equipment | |
| Reduce vehicle idling at park entrances | |
| Enforce "no idling" policies for buses | |
| Reduce equipment use | |
| **Waste** | |
| Expand recycling program in park | Reduction in landfill $CH_4$<br><br>Education for park and concessionaire employees and visitors<br><br>Cost Savings<br><br>"Upstream" energy and carbon sequestration benefits as well |
| Compost yard trimmings and food scraps from park and concessionaire food services | |
| Reduce paper use in park (rely more on electronic transmission of information, use double-sided printers and copiers) | |
| Reuse materials in park (wood waste, used brick, glass for roads, cardboard boxes) | |
| Purchase items in bulk to reduce the overall need for packaging materials | |
| Compress recycled materials to reduce trips to recycling center in Las Vegas | |
| **Forestry** | |
| Continue prescribed burns[a] | Helps prevent catastrophic forest fires |
| Burn forests when fuel is green/wet | Reduces amount of fuel burned |
| **Education / Outreach** | |
| Educate park staff on climate change during orientation, workshops, or brown bags | Education to employees |
| Provide outreach materials to visitors on climate change (e.g., general or CFP information) | Education to visitors |
| Post climate change info on park web site | Education to visitors and virtual visitors |

[a] Prescribed burns may actually cause increases in $CO_2$ emissions in the short term; however, by reducing the fuel load in the forests, prescribed burns can help prevent major forest fires and the large amounts of $CO_2$ that is emitted by such fires. Thus, in the long run, prescribed burns can reduce GHG emissions.

[5] Switching to biodiesel as an energy source was also considered as a potential option. However, due to trade-offs in the entire life-cycle of biodiesel fuel, it is unclear whether this fuel offers GHG benefits.

# 1 INTRODUCTION

## 1.1 BACKGROUND & PURPOSE

Since the late 1990s, the National Park Service (NPS) and Environmental Protection Agency (EPA) have undertaken efforts to help parks improve their management of natural resources, implement green practices, and become better stewards of the environment. Examples of these initiatives include the NPS Natural Resource Challenge, the NPS Environmental Leadership Program, and EPA's longstanding support to parks and outdoor enthusiasts on climate change. In 2002, the NPS Green Partners Program evolved out of the NPS Environmental Leadership Program. The main objective of the Green Partners Program was to identify key partners that could assist parks in accelerating the implementation of green strategies and practices. As part of this program, NPS partnered with the EPA to launch the Climate Friendly Parks (CFP) pilot project in 2002. The CFP Program has four key objectives:

- Supporting the President's Climate Change Initiative
- Supporting a Federal model of environmental excellence
- Achieving greenhouse gas (GHG) reductions and energy savings
- Protecting natural resources

These objectives are achieved as individual parks partner with EPA and NPS national programs to become more climate-friendly. The CFP Program assists parks in educating staff about the issue of climate change, estimating baseline emissions of GHGs, identifying opportunities to reduce park emissions, and developing materials and methods to inform the public about the climate-friendly actions underway in the park.

One of the most important steps for parks interested in becoming more climate-friendly is conducting an inventory of GHG emissions. This step is critical because until park staff and concessionaires know which activities are contributing to emissions and the relative magnitude of emissions from each source, they will not know where to focus their emissions reduction efforts. In addition, the inventory will provide Zion and Xanterra staff with a baseline against which future actions to reduce emissions may be compared.

This report presents GHG emissions associated with activities in Zion National Park. Zion National Park follows Gateway National Recreation Area and Glacier National Park as the third U.S. park to participate in the CFP Program and to develop an inventory of GHG emissions. By participating in the program, Zion helps lead the way toward implementation of more climate-friendly practices in parks nationwide. Zion has, in fact, already begun to lead the way by incorporating energy efficient systems into two of its buildings, initiating a visitor shuttle bus system, and carrying out an active recycling program, among other successes. Many opportunities still exist to help further both the CFP Program's objectives and Zion's own mission to "…protect and preserve the valuable cultural, geologic, vegetation and wildlife resources while providing safe, sustainable and cost-efficient access for visitors experience and enjoyment. In addition, the park aims to educate both visitors and the general public about this exceptional environment" (NPS 2004a).

## 1.2 RATIONALE FOR INVENTORYING GHG EMISSIONS

A criteria air pollutant emissions inventory was completed for Zion National Park for the year 2000 (CE-CERT 2003). These pollutants,[6] which are considered harmful to public health and the environment but do not directly affect climate change, are regulated under the Clean Air Act. Emissions inventories originally focused on criteria air pollutants to ensure compliance with regulations and to help mitigate these emissions; however, international efforts to address global warming have prompted the development of national, state, and local GHG inventories.

Actions to address increasing GHG emissions began in the early 1990s. In 1992, the United States joined with 154 other nations at the United Nations Conference on Environment and Development (also known as the Earth Summit) in signing the United Nations Framework Convention on Climate Change (UNFCCC). Later that year, the United States became the first industrialized nation to ratify the UNFCCC Treaty, which came into force on March 21, 1994. The UNFCCC commits signatories to stabilizing anthropogenic GHG emissions to "levels that would prevent dangerous anthropogenic interference with the climate system." To facilitate these goals, Article 4-1 of the UNFCCC treaty requires that all parties to the UNFCCC develop, periodically update, and make available to the Conference of the Parties, national inventories of anthropogenic emissions of all GHGs not controlled by the Montreal Protocol.

The U.S. government has published annual GHG inventories – most recently the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (EPA 2004) – to fulfill its obligation under the UNFCCC. This series of national inventories tracks the emissions of each GHG, by source, and provides a benchmark for efforts to reduce emissions. In 2002, the Bush Administration set forth a national goal of reducing GHG intensity by 18 percent over the next ten years.[7] In an effort to achieve national GHG reductions, EPA has set voluntary goals for GHG emissions reduction through its "Climate Leaders" initiative, set forth in February 2002. Under this program, EPA encourages companies to measure and reduce GHG emissions. To the extent that Zion can inventory and then track changes in GHG emissions over time, the park may be able to reduce emissions and set an

**Box 1.1: Examples of Action Items Identified at CFP Workshop**

**Transportation**
- Employ alternative fuels in vehicles
- Supply loaner bikes for employees
- Reduce vehicle idling
- Improve fleet management
- Expand shuttle bus system
- Increase bicycle accessibility

**Energy & Water Conservation**
- Automate controls and retrofit the Headquarters/ Admin building
- Install low-flow fixtures everywhere
- Explore shade structure use
- Adopt sustainable design (LEED standards) in existing and new buildings
- Finish installing 70% efficient lighting in Admin building, residences, concessions, and other buildings

**Waste Management**
- Establish a green team
- Complete ISWAP
- Educate local community, staff, and concessionaires
- Increase green purchasing/reuse of materials and of the vehicle fleet
- Expand recycling program to include visitors
- Ramp up the green filter

**Outreach & Education**
- Plan a 2-day community event for Earth Day focusing on climate change
- Improve in-house education on climate change through a Zion message program
- Educate visitors about climate change impacts by expanding Field Institute classes

[6] Criteria air pollutants include sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), lead (Pb), ground-level ozone ($O_3$), and particulate matter (PM).
[7] This intensity reduction goal focuses on slowing the growth of GHG emissions and is measured by the ratio of GHG emissions to economic output.

example for park visitors.

In May 2004, Zion National Park, NPS, and EPA held a CFP workshop at Zion, located in the Zion Lodge. Park and concessionaire employees, with guidance from EPA and NPS staff and other climate change experts, identified a number of climate-friendly action items that they would like to undertake at Zion as both short and long-term goals. Some of these are listed in Box 1.1. Implementing such programs would lead to significant reductions in GHG emissions, which could be measured using this inventory as a baseline.

In conjunction with these action items, Zion can also reach other targets, such as the implementation of an Environmental Management System (EMS). The CFP Program and NPS EMS efforts are mutually compatible and beneficial. According to Executive Order 13148: Greening the Government Through Leadership in Environmental Management, federal agencies must integrate environmental accountability into day-to-day decision-making and long-term planning. This means that each park must implement an EMS by December 31, 2005. The park EMS must have measurable environmental goals, objectives, and targets that are reviewed and updated annually, and EMS performance measures must be incorporated into audit protocols.

Inventorying GHG emissions fits into the EMS framework and provides a basis for park commitments to reduce emissions; as such, the primary goal of this document is to provide Zion with a foundation for identifying and implementing activities to reduce emissions. The EMS continuous improvement management approach promises to enhance results of the climate initiative, while the park's climate action plan provides the park with detailed inputs to its EMS. Both programs benefit from this joint pursuit.

This inventory provides an overview of emissions at Zion in 2002; however, the inventory does not reflect all sources of emissions. The Zion inventory includes the most significant sources of emissions at the park, but does not include a couple of minor sources due to data and resource limitations. Because data availability, contractor resources, and park staff time are inconsistent across parks, some park inventories are more comprehensive than others. Specific sources that have been excluded from this inventory include refrigeration and air conditioning, solvent use, agriculture, and wastewater. Readers should refer to Table 1.2 for a more detailed explanation of emission sources included and excluded in the Zion Inventory.

## 1.3 Park Description

Zion National Park is located in southwestern Utah. The name Zion means "a place of safety or refuge" in Hebrew, which is fitting for its characteristic deep and narrow canyons, striking cliffs, and plateaus. Zion was first established as Mukuntuweap National Monument in 1909. The name was later changed to Zion National Monument in 1918, and then expanded and designated a National Park in 1919. The Kolob Canyons section of the park was added in 1956[8] (NPS 2004a).

Zion spans 146,597 acres (229 square miles) comprised of two major canyons: Zion in the south and Kolob in the northwest (see map in Figure 1.1). The southern area of the park is lower in elevation consisting of desert areas with mesas and red-rock canyons, while the northern sections include higher forest-covered plateaus. Park elevations range from 3,666 to 8,726 feet above sea level (NPS 2004a).

The park includes four entrances and 57 miles of paved and gravel roads. The entrances include: (1) the South Springdale entrance into the Zion Canyon, which is the most visited area in Zion; (2) the East entrance, which is connected to the Zion Canyon by way of the mile-long Zion/Mt. Carmel Tunnel; (3) the

[8] Kolob Canyons was previously established as a National Monument in 1937.

Kolob Canyons entrance; and (4) the North entrance through the Upper Kolob Plateau, which is the least traveled entrance point. In 2002, the park welcomed approximately 2.5 million visitors, or an average of 7,160 visitors per day (NPS 2004b). The majority (82 percent) of these visitors came to Zion during the peak season of April through October. Zion offers a wide range of activities for visitors, including hiking, camping, climbing, horseback riding, bicycling, birdwatching, photography, and various ranger-led activities.

In addition to park-led activities and operations, concessionaires offer other services to visitors in the park. The major concessionaire, Xanterra, operates the only in-park lodge, Zion Lodge. Canyon Trail Rides offers guided horseback rides in Zion Canyon between March and October. Parks Transportation, Inc. runs the park's visitor shuttle system, which operates along the six-mile long Zion Canyon Scenic Drive (closed off to visitor vehicles between April and October). The Zion Natural History Association, a non-profit that supports Zion's educational programs, sells interpretive products in the park visitor centers and the Zion Human History Museum. In 2002, the park employed about 150 full-time and 75 seasonal employees, compared to about 70 full-time and 100 seasonal staff employed by Xanterra (Lopez 2004, Stewart 2004). Some park employees reside in the park; there are 19 permanent and 12 seasonal residences.

## 1.4 INVENTORY METHODOLOGY

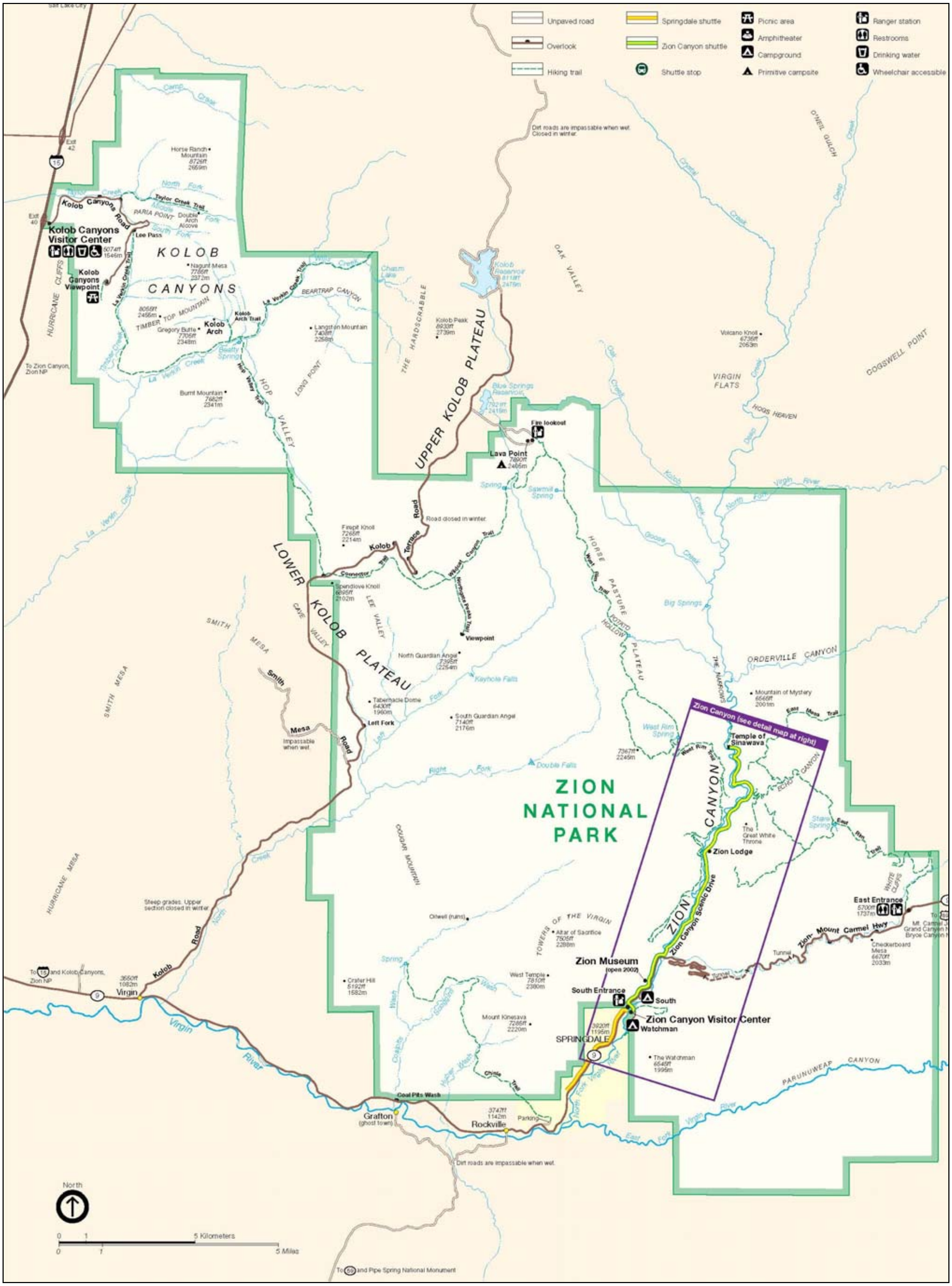
The methodology used to develop Zion's GHG emissions inventory involved the following steps:

1) Developed a data collection form of items needed to estimate GHG emissions at Zion;
2) Requested park and concessionaire data;
3) Visited Zion in March 2004 to collect data from park and concessionaire personnel;
4) Reviewed data provided;
5) Attempted to fill data gaps through conversations with park staff and independent research;
6) Estimated GHG emissions;
7) Presented preliminary emission results at CFP workshop in May 2004;
8) Revised estimates; and
9) Developed an inventory report.

Data were collected and reported separately by park-owned, park-leased (i.e., GSA and Acme leased vehicles), residence, concessionaire, and visitor activities. Emissions attributed to concessionaires refer to Xanterra's operations. Although the concessionaire, Parks Transportation, Inc., operates the visitor shuttle bus system, emissions for these buses are included under park operations because the park implemented this program and require visitors to use it. Similarly, emission contributions by the Zion Natural History Association were included under park-owned emission totals. This concessionaire operates within park-owned buildings where the park handles heating and cooling operations. Emissions attributed to the horseback riding concessionaire, Canyon Trail Rides, were deemed to small to quantify.

Zion National Park chose to inventory emissions for the year 2002. The approach used to measure GHGs from anthropogenic (human activities) at Zion is consistent with the methods used at the state and national levels.

**Figure 1.1: Map of Zion National Park**



# 1.5 OVERVIEW OF GHG SOURCES & DISCUSSION OF SOURCES INCLUDED IN INVENTORY

Naturally occurring GHGs include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), water vapor, and ozone ($O_3$). Human activities (e.g., fuel combustion in stationary and mobile sources, agriculture, and waste generation) lead to increased concentrations of these gases in the atmosphere. In addition, there are other more powerful GHGs—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) (i.e., chemicals composed of carbon and fluorine), and sulfur hexafluoride ($SF_6$)—that are created by various industrial processes. The ability of a gas to trap heat in the atmosphere is measured by its Global Warming Potential (GWP). GWP is a weighting factor used to measure the ability of a gas to trap heat in the atmosphere. This ability is measured relative to the most commonly occurring GHG: $CO_2$, which has a GWP of 1. As a comparison, $CH_4$ has a GWP of 21. Therefore, one unit of $CH_4$ is as effective at trapping heat in the atmosphere as 21 units of $CO_2$. Table 1.1 presents a list of GHGs and their associated GWPs. The GHGs inventoried in this report include $CO_2$, $CH_4$, and $N_2O$.

**Table 1.1: Global Warming Potentials**

| Gas | GWP[a] |
|---|---|
| Carbon dioxide ($CO_2$) | 1 |
| Methane ($CH_4$)[b] | 21 |
| Nitrous oxide ($N_2O$) | 310 |
| HFC-23 | 11,700 |
| HFC-125 | 2,800 |
| HFC-134a | 1,300 |
| HFC-143a | 3,800 |
| HFC-152a | 140 |
| HFC-227ea | 2,900 |
| HFC-236fa | 6,300 |
| HFC-4310mee | 1,300 |
| $CF_4$ | 6,500 |
| $C_2F_6$ | 9,200 |
| $C_4F_{10}$ | 7,000 |
| $C_6F_{14}$ | 7,400 |
| $SF_6$ | 23,900 |

Source: IPCC 1996[9]
[a] 100-year time horizon
[b] The $CH_4$ GWP includes the direct and indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of $CO_2$ is not included.

In accordance with the GHG emission sources and sinks reported by the Intergovernmental Panel on Climate Change (IPCC) in *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997), EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (2004), and EPA's *Emissions inventory Improvement Program Guidelines, Vol. VIII Estimating Greenhouse Gas Emissions* (2003), GHG emission

[9] The GWPs listed above are from IPCC's Second Assessment Report (SAR). These were updated by IPCC in the Third Assessment Report (TAR); however, the UNFCCC reporting guidelines for national inventories continue to require the use of the SAR GWPs so that current estimates of aggregated GHGs are consistent with estimates developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported using SAR GWP values.

sources and sinks include the following activities: energy, industrial processes, solvents and other product use, agriculture, land use change and forestry, and waste. The specific emission sources under these activities are included in Table 1.2.

The sources included in this inventory were based on (1) whether the activity occurs at the park; (2) whether opportunities exist for reducing emissions from the activity;[10] (3) whether emissions from each source were significant enough to warrant substantial data collection and emission estimation efforts; and (4) whether data were available for collection. With respect to the first criterion, coal mining, natural gas and oil systems, international bunker fuels, most of the industrial process source categories, rice cultivation, agricultural residue burning, and wastewater were not applicable to Zion. With respect to the second criterion, emissions of HFCs and PFCs from the consumption of substitutes for ozone-depleting substances used in refrigeration and air conditioning were not estimated for Zion because there are currently very few options to reduce these emissions. On the third point, other sources, such as solvent use, enteric fermentation and manure management (for horses and other animals in the park), fertilizer use, and wastewater treatment were deemed too small to quantify. As far as the fourth criterion is concerned, inclusion of all applicable and significant sources was limited by a shortened timeframe for gathering data combined with difficulties obtaining some of the necessary data from park and concessionaire personnel.

Table 1.2 presents the GHG emission sources, their relevance for Zion, and whether or not they were estimated. It is important to note that the sources included in the Zion Inventory represent the most significant sources of GHG emissions and sinks in the park. Some relevant sources were excluded because they were not determined to be significant sources at Zion, and/or sufficient data were not available to develop estimates.

[10] This criterion was established when the budget and scope of the inventory were assessed. The goal of the program is to educated the park and the visitors and to encourage both audiences to take actions to reduce emissions. Thus, the sources of highest priority are those that could offer the greatest education and mitigation potential.

**Table 1.2: GHG Emission Sources**

| Pollutant/Source Category | Relevant for Zion | Estimated for Zion | Reason Relevant Sources Missing from Inventory |
|---|---|---|---|
| **GHG Source** | | | |
| **Energy** | | | |
| $CO_2$, $CH_4$, and $N_2O$ from Stationary Combustion | Y | Y | |
| $CO_2$, $CH_4$, and $N_2O$ from Mobile Combustion | Y | Y | |
| Highway Vehicles | Y | Y[a] | *Residences*: Necessary data for estimating emissions from vehicles owned by residences within park boundaries were unavailable. |
| Nonroad Vehicles | Y | Y[a] | *Residences*: Necessary data for estimating emissions from vehicles owned by residences within park boundaries were unavailable.<br><br>Aviation emissions were not quantified due to the difficulty in obtaining the necessary data and quantifying emissions given resources available. |
| $CH_4$ from Coal Mining and Natural Gas and Oil Systems | N | N | |
| $CO_2$ from Natural Gas Flaring | N | N | |
| $CO_2$, $CH_4$, and $N_2O$ from International Bunker Fuels | N | N | |
| **Industrial Processes** | | | |
| $CO_2$ from the Production of Cement, Lime, Iron and Steel, and Titanium Dioxide; Limestone and Dolomite Use; Soda Ash Manufacture & Consumption; Ammonia Production & Urea Application; Ferroalloys; and $CO_2$ Consumption | N | N | |
| $CH_4$ from Silicon Carbide and Petrochemical Production | N | N | |
| $N_2O$ from Nitric and Adipic Acid Production | N | N | |
| $CO_2$ and PFCs from Aluminum Production | N | N | |
| HFCs and PFCs from Consumption of Substitutes for Ozone-Depleting Substances (Refrigeration & Air Conditioning) | Y | N | Opportunities do not exist to reduce emissions from this activity (e.g., no alternatives to these substitutes are currently available). |
| PFC, HFC, and $SF_6$ from Semiconductor Manufacture and HFC-23 from HCFC-22 Production | N | N | |
| $SF_6$ from Electric Power Transmission & Distribution and Magnesium Production & Processing | N | N | |
| **Solvent Use** | Y | N | Deemed too small to quantify given resources available. |
| **Agriculture** | | | |
| $CH_4$ from Enteric Fermentation | Y | N | Deemed too small to quantify given resources available. |
| $CH_4$ and $N_2O$ from Manure Management | Y | N | Deemed too small to quantify given resources available. |
| $CH_4$ from Rice Cultivation | N | N | |

| Pollutant/Source Category | Relevant for Zion | Estimated for Zion | Reason Relevant Sources Missing from Inventory |
|---|---|---|---|
| $N_2O$ from Agricultural Soil Management (Fertilizer Use) | Y | N | Deemed too small to quantify given resources available. |
| $CH_4$ and $N_2O$ from Agricultural Residue Burning | N | N | |
| **Land-use Change and Forestry** | | | |
| Changes in Forest Carbon Stocks (including prescribed burning and wildfires) | Y | Y[a] | Grass burning emissions were not quantified as they were deemed too small to quantify given resources available. |
| Changes in Carbon Stocks in Urban Trees, Agricultural Soil Carbon Stocks, and Carbon Stocks from Landfilled Yard Trimmings | N | N | |
| **Waste** | | | |
| $CH_4$ from Landfills | Y | Y | |
| $CO_2$ and $N_2O$ Waste Combustion [b] | Y | Y | Included under changes in forest carbon stocks because burning included brush and limbs only. |
| $CH_4$ from Wastewater Treatment | N | N | No wastewater treatment plant in the park. |
| $N_2O$ from Human Sewage | N | N | No wastewater treatment plant in the park. |

Note: Y = Yes; N = No.
[a] Estimated where data allowed.
[b] Sometimes included under the Energy sector.

## 1.6 OVERALL EMISSIONS AND SINKS AT ZION NATIONAL PARK

GHG emissions for Zion were estimated using methodologies consistent with those outlined in the *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997), EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (2004), and EPA's *Emissions inventory Improvement Program Guidelines, Vol. VIII Estimating Greenhouse Gas Emissions* (2003). Emissions were estimated for stationary combustion (i.e., burning of fuel for heating, cooling, and cooking in buildings and campfires), mobile combustion (i.e., highway and nonroad vehicle use within the park), landfilled waste (i.e., waste generated in the park but disposed at area landfills), and burning of forests. Carbon flux in Zion's forests (i.e., the difference between the amount of carbon that is sequestered from the atmosphere and stored in the forests and the amount that is emitted through forest decay, thinning, and burning) was also estimated for Zion. The results of this analysis showed that Zion's forests stored more carbon than they released in 2002, thus making the forests a net sink.

Emission results below are presented overall for both emissions and sinks and then separately for emission sources and sinks (i.e., the carbon flux in Zion's forests). The reason for evaluating carbon flux separately is because this inventory's aim is to focus on GHGs emitted to the atmosphere from activities within the park that present opportunities for GHG reduction. For example, Zion has control over the type and quantity of its fuel, its vehicle fleet and miles traveled, and the quantity of waste landfilled or recycled. Because the CFP program is focused on helping parks reduce emissions, carbon flux was treated as a separate, but important, component of the Zion inventory. In addition, a great deal of uncertainty is inherent in the forest carbon flux estimates.

Based on the results of this emissions analysis, Zion emitted approximately 2,839 metric tons of carbon equivalent (MTCE) in 2002; when accounting for forest carbon additions and removals (i.e. net carbon flux), Zion's net emissions were 160 MTCE. Table 1.3 presents overall emissions and sinks by source and by gas for Zion. Although Zion emitted about 2,024 MTCE of $CO_2$ from stationary and mobile combustion (506 and 1,518, respectively) in 2002, the sequestering of 2,679 MTCE by the forests offset these emissions and resulted in overall $CO_2$ sequestration of 654 MTCE. Overall $CH_4$ and $N_2O$ emissions were 667 and 147 MTCE, respectively. Burning accounted for the majority of these non-$CO_2$ emissions—65 percent of $CH_4$ and 68 percent of $N_2O$. The next largest source of $CH_4$ was landfilled waste (33 percent); mobile combustion contributed to 31 percent of overall $N_2O$ emissions.

**Table 1.3: Overall GHG Emissions and Sinks**

| Source | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Stationary Combustion** | **506.4** | **8.5** | **2.4** | **517.2** |
| Direct Combustion | 305.0 | 8.5 | 2.4 | 315.9 |
| Indirect – Purchased Electricity | 201.3 | NE | NE | 201.3 |
| **Mobile Combustion** | **1,518.2** | **3.7** | **45.2** | **1,567.1** |
| Highway Vehicles | 1,508.6 | 3.7 | 45.1 | 1,557.4 |
| Nonroad Vehicles/Equipment | 9.6 | + | 0.1 | 9.7 |
| **Landfilled Waste** | **NA** | **220.1** | **NA** | **220.1** |
| **Forestry** | **(2,679.0)** | **435.0** | **99.5** | **(2,144.5)** |
| Forest ($CO_2$ Flux) | (2,679.0) | NA | NA | (2,679.0) |
| Burning ($CH_4$ and $N_2O$ only) | NA | 435.0 | 99.5 | 534.5 |
| **TOTAL GROSS EMISSIONS*** | **2,024.5** | **667.3** | **147.1** | **2,839.0** |
| **TOTAL NET EMISSIONS*** | **(654.4)** | **667.3** | **147.1** | **160.0** |

Note: Totals may not sum due to independent rounding. Parentheses indicate net carbon sequestration.
NE = Not Estimated. NA = Not Applicable. + Does not exceed 0.05 MTCE.
* Gross emissions do not include forest carbon flux. Net emissions reflect the subtraction of net carbon flux from gross emissions.

Tables 1.4 and 1.5 present the emissions and sinks separately for Zion. Focusing on emission sources only, Zion emitted roughly 2,839 MTCE in 2002. Highway vehicles comprised the majority of emissions with 55 percent, followed by $CH_4$ and $N_2O$ from burning (19 percent), stationary combustion (11 percent), landfilled waste (8 percent), and purchased electricity (7 percent) as shown in Figure 1.2. $CO_2$ accounted for the largest share of emissions (71 percent), while $CH_4$ and $N_2O$ accounted for 24 and 5 percent of emissions, respectively. $CO_2$ typically comprises an even larger share of emission at the state and national levels; however, the estimation of $CH_4$ and $N_2O$ from burning—which had the largest impact on gross $CH_4$ and $N_2O$ emissions from the park – has not yet been incorporated into these inventories. Accounting for these emissions would increase the significance of $CH_4$ and $N_2O$ in overall emissions, although $CO_2$ would remain the dominant gas.

The net $CO_2$ flux from the forests was -2,679 MTCE in 2002, as shown in Table 1.5. This indicates that the forests sequestered more carbon than they emitted through decay, thinning, or burning.

**Table 1.4: Gross GHG Emissions**

| Source | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Stationary Combustion** | **506.4** | **8.5** | **2.4** | **517.2** |
| Direct Combustion | 305.0 | 8.5 | 2.4 | 315.9 |
| Indirect – Purchased Electricity | 201.3 | NE | NE | 201.3 |
| **Mobile Combustion** | **1,518.2** | **3.7** | **45.2** | **1,567.1** |
| Highway Vehicles | 1,508.6 | 3.7 | 45.1 | 1,557.4 |
| Nonroad Vehicles/Equipment | 9.6 | + | 0.1 | 9.7 |
| **Landfilled Waste** | **NA** | **220.1** | **NA** | **220.1** |
| **Forestry** | **NA** | **435.0** | **99.5** | **534.5** |
| Burning ($CH_4$ and $N_2O$ only) | NA | 435.0 | 99.5 | 534.5 |
| **TOTAL** | **2,024.5** | **667.3** | **147.1** | **2,839.0** |

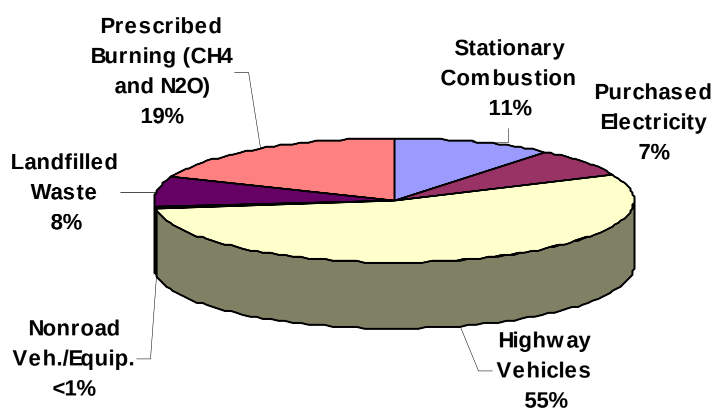
Note: Totals may not sum due to independent rounding.
NE = Not Estimated. NA = Not Applicable. + Does not exceed 0.05 MTCE.

**Table 1.5: GHG Emissions and Net $CO_2$ Flux from Standing Forests, Burning, and Thinning**

| Source Category | Emissions/Sequestration (MTCE) |
|---|---|
| Forest ($CO_2$ Flux) | (2,679) |
| Burning ($CH_4$ and $N_2O$ only) | 535 |
| **TOTAL** | **(2,144)** |

Note: Parentheses indicate net carbon sequestration

**Figure 1.2: Gross Emissions by Source**



## 1.7 REPORT STRUCTURE

Inventory estimates for Zion are organized by the source category and then by the specific activities generating emissions. The structure of this inventory deviates from typical GHG inventories, which report $CO_2$ emissions for stationary and mobile combustion separately from $CH_4$ and $N_2O$ emissions. The reason for this change is to make it easier for park employees to identify and absorb information pertaining to their areas of expertise (e.g., facility management). Each chapter provides an overview of the source category, results, and a brief discussion of the methodology and data sources used to estimate emissions. Appendices A through D provide more detailed information on activity data and emission factors used in the calculations.

The remainder of this report is structured as follows:

- Chapter 2: Stationary Combustion
- Chapter 3: Mobile Combustion
- Chapter 4: Waste Disposal
- Chapter 5: Forestry
- Chapter 6: References
- Appendix A: Stationary Combustion Background Tables
- Appendix B: Mobile Combustion Background Tables
- Appendix C: Waste Disposal Background Tables
- Appendix D: Forestry Background Tables

# 2 STATIONARY COMBUSTION

Greenhouse gases (GHGs) are emitted when fuels are burned for energy by both stationary and mobile sources. Stationary emissions associated with combustion occurring within park boundaries result from activities such as heating buildings, cooking, and having campfires. Combustion-related emissions that occur as a result of park activities but are actually emitted outside of park boundaries, such as at power generation facilities, are referred to as indirect emissions. At Zion, emissions from stationary combustion result from the burning of the following:

- propane in water heaters, boilers, and backup generators in park-owned buildings;
- propane and distillate fuel for cooking and heating in Zion Lodge buildings;
- propane for heating seasonal and permanent residences;
- waste oil at the NPS maintenance yard;
- wood in campfires;
- propane in visitor motor homes; and
- various fuels used by power plants to produce electricity consumed in the park.

Because the peak season for visitors occurs between April and October, fuel use at the lodge, campsites, and other park and concessionaire operations within the park is highest during these months of the year.

Zion has already taken steps to reduce its direct and indirect emissions from stationary sources. The park designed its new visitor center with energy-efficient controls to reduce its dependence on air conditioning and to take advantage of daylight and solar energy. Photovoltaic panels at the visitor center not only provide the building with electricity, but also supply electricity back to the grid. Xanterra, the park's main concessionaire, elected to use Blue Sky Wind Power to supply 10 percent of their electricity purchases at Zion Lodge. Because the generation of wind power does not result in carbon emissions, electricity-related emissions for Zion Lodge were 13 metric tons of carbon equivalent (MTCE) lower than what they otherwise would have been. Despite all of these improvements, there are still some opportunities for additional facility-related GHG reductions (see Box 2.1).

**Box 2.1: Options for Further Reductions**

Zion can reduce even more GHG emissions from stationary sources by:

- Retrofitting other park buildings (e.g., Administration building, residences) with energy-efficient features, such as motion sensors, increased insulation, and efficient air conditioning systems
- Taking advantage of solar energy in the Southwest
- Switching a portion of fuel use to natural gas, which has a lower carbon intensity than propane

For this inventory, we estimated carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) emissions from stationary fuel combustion and $CO_2$ emissions from purchased electricity. We limited our estimates of emissions from purchased electricity to $CO_2$ for two reasons. First, whereas $CO_2$ emissions from stationary combustion are primarily dependent on the carbon content of the fuel, emission pathways of $CH_4$ and $N_2O$ from purchased electricity are much more complex. The characteristics of the fuel, combustion technology, control technology, environmental conditions, and other factors can affect the amount of $CH_4$ and $N_2O$ emitted. This information was not available at the level of detail necessary to estimate $CH_4$ and $N_2O$ from indirect combustion. Second, emissions of $CH_4$ and $N_2O$ from purchased electricity are very small in comparison to $CO_2$ emissions from stationary combustion. In the United States, emissions of $CH_4$ and $N_2O$ account for only 0.4 percent of emissions from stationary fuel combustion, with $CO_2$

**Box 2.2: Saving Energy in Zion's Visitor Center**

Zion is already taking the first steps in reducing it's energy use by utilizing a state-of-the-art cooling system in its visitor center. Building features include:

- A well-insulated building to help minimize heating and cooling loads.
- Optimally-placed windows to maximize natural light. Besides reducing electricity use for lighting, the natural light helps warm the building in the winter. In the summer, overhangs help minimize excessive heating by the sun.
- Strategically designed ventilation helps maintain a comfortable room temperature without using electrical cooling systems.
- Additional cooling needs are met through the use of cooltowers, which employ natural convection and evaporation processes. Water is pumped to the top of the tower and evaporates, cooling the air. The cool air falls, causing the warm air to rise and escape through the vents. This system requires a minimal amount of electricity (to operate the water pump).

representing nearly all GHG emissions from this source (EPA 2004). Because a more simplified method using specific factors is available for estimating direct $CH_4$ and $N_2O$ from stationary combustion occurring within the park boundaries, these emissions were calculated.

The sections that follow discuss emissions from stationary combustion and provide an overview of the methodology and data sources used in the calculations.

## 2.1 RESULTS

In 2002, 517 metric tons of carbon equivalent (MTCE) from stationary combustion sources were emitted by Zion National Park, as shown in Table 2.1. This quantity represents 18 percent of gross GHG emissions from Zion. Nearly all emissions from stationary combustion (98 percent) were $CO_2$, which is consistent with national and most state emissions inventories. As explained above, sources of stationary combustion emissions include those within park boundaries (e.g., boilers, water heaters, campfires) as well as purchased electricity. Of Zion's total emissions from stationary combustion, emissions from direct fuel use activities within park boundaries (316 MTCE) were greater than those from purchased electricity (about 200 MTCE).

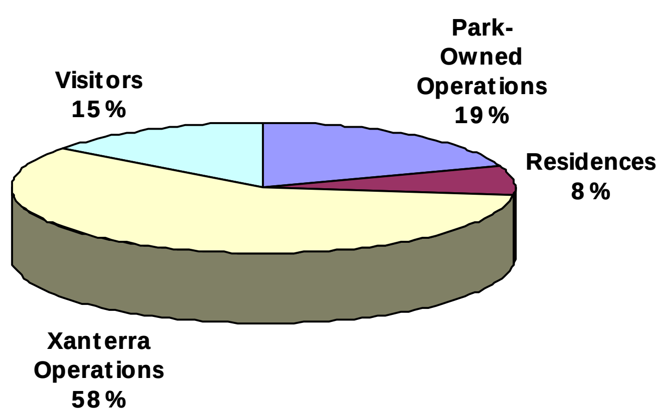
**Table 2.1: Summary of $CO_2$, $CH_4$, and $N_2O$ Emissions from Stationary Combustion**

| Source / Operation | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Fuel Combustion in Park** | **305.0** | **8.5** | **2.4** | **315.9** |
| Park-Owned Operations | 31.0 | 7.6 | 1.6 | **40.2** |
| Residences | 17.0 | 0.1 | 0.1 | **17.1** |
| Xanterra Operations | 180.9 | 0.6 | 0.5 | **182.0** |
| Visitors | 76.1 | 0.3 | 0.2 | **76.6** |
| **Purchased Electricity** | **201.3** | **NE** | **NE** | **201.3** |
| Park-Owned Operations | 60.4 | NE | NE | **60.4** |
| Residences | 21.9 | NE | NE | **21.9** |
| Xanterra Operations | 119.0 | NE | NE | **119.0** |
| Visitors | IE | NE | NE | **NE** |
| **TOTAL** | **506.4** | **8.5** | **2.4** | **517.2** |
| **Park-Owned Operations** | **91.4** | **7.6** | **1.6** | **100.6** |
| **Residences** | **38.9** | **0.1** | **0.1** | **39.0** |
| **Xanterra Operations** | **299.9** | **0.6** | **0.5** | **301.0** |
| **Visitors** | **76.1** | **0.3** | **0.2** | **76.6** |

Note: Totals may not sum due to independent rounding.
NE = Not Estimated.
IE = Included Elsewhere. Emissions from visitor electricity use are captured in the estimates for Xanterra and park-owned operations.

As Figure 2.1 shows, Xanterra's concessionaire operations accounted for the majority (58 percent or 301 MTCE) of GHG emissions from stationary sources at Zion. Fuel and electricity usage in park-owned buildings accounted for about 100 MTCE, followed by visitor RV propane emissions (77 MTCE)[11] and in-park seasonal and permanent residences' emissions (39 MTCE). Higher fuel use and electricity demand by the Xanterra-run Zion Lodge than by NPS-owned operations in the park may be attributed to the size and number of facilities managed by Xanterra compared with the park facilities. As part of Zion Lodge, Xanterra manages several visitor accommodations including the main lodge building, which consists of a restaurant and café; two motel buildings; 40 cabins; and a dormitory for employees.

**Figure 2.1: Stationary Combustion Emissions by Operation**




[11] "Stationary" RV emissions include those emissions associated with running RV generators. Emissions due to the transport of RVs are included under the mobile source category.

The majority, or 61 percent, of emissions from stationary sources at Zion were from fuel combustion within the park. The primary contributors to direct emissions were Xanterra operations and visitor activities. Most of the fuel consumed by stationary sources within the park was propane, which accounted for 81 percent of emissions (see Table 2.2). $CH_4$ and $N_2O$ emissions from park-owned operations were much higher than they were for the other operations primarily due to wood burned for campfires. Park-owned operations accounted for about 10 percent of petroleum emissions (from propane and lubricants) and all of the wood emissions in the park.

**Table 2.2: Summary of $CO_2$, $CH_4$, and $N_2O$ Emissions from Stationary Combustion within Park Boundaries, by Fuel Type**

| Source / Operation | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Propane** | **248.3** | **0.8** | **0.7** | **249.9** |
| Park-Owned Operations | 30.6 | 0.1 | 0.1 | **30.8** |
| Residences | 17.0 | 0.1 | 0.1 | **17.1** |
| Xanterra Operations | 124.6 | 0.4 | 0.4 | **125.4** |
| Visitors | 76.1 | 0.3 | 0.2 | **76.6** |
| **Distillate Fuel** | **56.3** | **0.2** | **0.1** | **56.6** |
| Xanterra Operations | 56.3 | 0.2 | 0.1 | 56.6 |
| **Lubricants** | **0.4** | **+** | + | **0.4** |
| Park-Owned Operations | 0.4 | + | + | **0.4** |
| **Wood** | **NA** | **7.5** | **1.5** | **9.0** |
| Park-Owned Operations | NA | 7.5 | 1.5 | **9.0** |
| **TOTAL** | **305.0** | **8.5** | **2.4** | **315.9** |
| **Park-Owned Operations** | **31.0** | **7.6** | **1.6** | **40.2** |
| **Residences** | **17.0** | **0.1** | **0.1** | **17.1** |
| **Xanterra Operations** | **180.9** | **0.6** | **0.5** | **182.0** |
| **Visitors** | **76.1** | **0.3** | **0.2** | **76.6** |

Note: Totals may not sum due to independent rounding.
NA = Not Applicable. + Does not exceed 0.05 MTCE.

## 2.2 METHODOLOGY AND DATA SOURCES

Emissions from stationary sources were estimated using data on fuel consumption and electricity purchases (from electricity bills) provided by the park and its key concessionaire, Xanterra. The sources of these data are presented in Table 2.3.

The Intergovernmental Panel on Climate Change (IPCC) provides guidance on the methodologies for estimating GHG emissions from stationary combustion (IPCC 1997). The methodology used to estimate $CO_2$ from direct combustion is based on the carbon content of each fuel, while the methodology used to estimate $CH_4$ and $N_2O$ is based on default IPCC emission factors for each primary fuel type (e.g. petroleum, biomass) and sector (e.g. residential).

To estimate $CO_2$ emissions from direct combustion in the park, data on petroleum consumption were converted to energy units (i.e., British thermal units, Btu) and multiplied by fuel-specific carbon content coefficients. The resulting total carbon in each fuel was multiplied by the fraction of carbon assumed to be oxidized to the atmosphere. See Appendix A for Zion fuel consumption information (Table A-1) and heat contents, carbon contents, and oxidation factors (Table A-2). Note that $CO_2$ emissions from wood combustion were not measured in an effort to maintain consistency with the IPCC methodology, which does not count $CO_2$ emissions from sustainable biogenic sources, such as wood (IPCC 1997).[12]

To estimate $CH_4$ and $N_2O$ emissions from direct stationary combustion, we followed the IPCC Tier 1 approach (IPCC 1997). First, petroleum energy data were adjusted from higher to lower heating values.[13] Wood data were converted to energy units by multiplying by the typical net calorific value for wood with 15 percent moisture for dry climates (IPCC 1997). Once fossil fuel and wood consumption data were in units of Btu, they were multiplied by IPCC fuel-specific emission factors (provided in Table A-2).

The methodology employed for estimating indirect $CO_2$ emissions from purchased electricity is described in the World Resources Institute and the World Business Council for Sustainable Development's *GHG Protocol Initiative* (2001), as well as EPA's Climate Protection Partnerships Division's *Climate Leaders Greenhouse Gas Inventory Protocol* (2002). First, the quantity of electricity purchased by the park, residences, and Xanterra (provided in Table A-3) was adjusted upward to reflect the amount of electricity that was originally generated to meet the electricity demand of the park. This step is necessary because approximately 9 percent of electricity is assumed to be lost in transmission and distribution before even reaching the park (EIA 2003). The resulting net electricity generated was multiplied by a $CO_2$ emission factor from EPA's eGRID model (2003).[14] This factor (provided in Table A-4) represents the average $CO_2$ emission rate for electricity in the WECC West Basin eGRID subregion, in which Zion National Park is located (EPA 2003).[15] The specific equations used in these calculations can be found in *Gateway National Recreation Area's Criteria Air Pollutant and Greenhouse Gas Emissions Inventory* (ICF 2003).

**Table 2.3: Data Sources for Estimation of GHG Emissions from Stationary Combustion**

| Source | Data Source |
|---|---|
| **Activity Data** | |
| Fuel use and electricity purchased data for Zion National Park, seasonal and permanent residences, and visitors | Starling 2004 |
| Zion Lodge fuel use and electricity purchased data | Stewart 2004 |
| **Factors** | |
| Heat contents, carbon contents, fraction oxidized, and heating value conversions | EPA 2004 |
| $CH_4$ and $N_2O$ emission factors and net calorific value for wood | IPCC 1997 |
| eGRID subregion $CO_2$ emission factor | EPA 2003 |
| Electricity loss factor | EIA 2003 |

[12] Carbon dioxide emissions from biomass burning are assumed to be equal to the carbon sequestered by its regrowth.
[13] Fuel use in the United States is typically measured in higher heating or gross calorific values (GCV). Since IPCC emission factors are based on fuel reported in lower heating or net calorific values (NCV), energy content in GCV was converted to NCV.
[14] http://www.epa.gov/cleanenergy/egrid/index.html
[15] The U.S. power grid is divided into 12 main regions within which electricity is commonly traded, called NERC (North American Electric Reliability Council) regions. EPA further divides these regions into subregions for the eGRID model. It is believed that average emission rate from the mix of resources used to generate electricity within each region currently provides the most accurate $CO_2$ emission factor.

# 3 MOBILE COMBUSTION

Mobile sources emit carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) from the combustion of fossil fuels. In 2002, the transportation sector was the single greatest emitter of greenhouse gases (GHGs) in Zion, accounting for 55 percent of the park's total gross emissions. Zion's mobile emission sources consisted primarily of highway vehicles driven within park boundaries by park and concessionaire personnel and by visitors. Nonroad mobile sources such as tractors, lawn mowers, backhoes, and other equipment also contributed to Zion's GHG emissions, but to a much smaller extent.

The two most important factors driving highway emissions are the number of vehicles and the miles traveled by each vehicle within park boundaries. Although individually park employees and concessionaires travel more miles within the park during the course of a year than most visitors would ever drive, the large amount of visitor travel in Zion caused visitor vehicle emissions to account for the largest share of mobile GHG emissions (77 percent). Therefore, taking steps to reduce visitor vehicle miles traveled within the park presents the greatest potential for emissions reductions. In 2000, Zion instituted a visitor shuttle system, which is an important first step in reducing mobile-related GHG emissions (see Box 3.1).

**Box 3.1: Saving GHGs while Transporting Visitors**

In the spring of 2000, Zion closed the Zion Canyon Scenic Drive to visitor vehicles and began requiring that visitors use the new propane-fueled shuttle system to travel along this 6-mile road between April and October. Not only does this shuttle system reduce noise, traffic, and parking problems in the busiest area of the park, but it also reduces Zion's GHG emissions. For every 100,000 mile reduction of visitor travel, approximately 12 MTCE is avoided.

Despite the large share of emissions from visitor vehicles, park and concessionaire vehicle use also offers opportunities for reducing emissions. Unlike visitor vehicle emissions, the park has some control over *what type* of vehicles are driven in addition to *how much* they are driven. By promoting alternative fuel use and reducing miles traveled by employees, the park and Xanterra will reduce GHG emissions to the atmosphere. In addition, this will demonstrate to visitors the park's commitment to reducing GHGs (see Box 3.2).

The sections that follow discuss the results of our analysis of emissions from mobile combustion and provide an overview of the methodology and data sources used in the calculations.

**Box 3.2: Setting an Example**

Zion and Xanterra are already pursuing a reduction of their GHG emissions through the initiatives outlined below as well as through the visitor shuttle system (described in Box 3.1). In addition to reducing the park's GHG emissions, these efforts provide visitors with an example of good environmental stewardship and demonstrate how effective GHG reductions can be achieved affordably and without disrupting day-to-day park operations and business practices.

**Reducing Vehicle Idling.** In order to reduce some of the vehicle idling (and resulting GHG emissions) as visitor and employee vehicles line up to enter the park, Zion has created a separate employee entrance that diverts employees out of the line. Additionally, the park has permanent signs in front of Zion Lodge to discourage tour buses from idling while they wait for passengers. *To further reduce vehicle idling, the park could (1) attempt to shorten the time spent paying entrance fees by issuing entrance permits online or using a swipe card system; (2) educate visitors to turn off their engines while waiting in line; and (3) enforce "no idling" policies for buses.*

**Using Alternative Fuels.** Although Zion's access to alternative fuels and alternative-fueled vehicles has been limited, the park does lease three ethanol/unleaded gasoline GSA vehicles; however, so far these vehicles have only been running on gasoline. *$CO_2$ emissions from these vehicles (2.8 MTCE) could be eliminated by fueling with ethanol.*

## 3.1 RESULTS

In 2002, Zion National Park emitted approximately 1,567 metric tons of carbon equivalent (MTCE) from mobile sources, as shown in Table 3.1. This quantity represents 55 percent of overall gross GHG emissions from Zion. Nearly all of these emissions (97 percent) were $CO_2$, analogous to the proportion seen in most national and state inventories. Emissions of $CH_4$ and $N_2O$ accounted for 0.2 and 3 percent, respectively, of total mobile combustion emissions. $CO_2$ emissions from mobile combustion are driven by fuel use, while $CH_4$ and $N_2O$ emissions are determined based on vehicle miles traveled (VMT), vehicle type, vehicle age, and control technology.

**Table 3.1: Summary of $CO_2$, $CH_4$, and $N_2O$ Emissions from Mobile Combustion**

| Source / Operation | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | **$CO_2$** | **$CH_4$** | **$N_2O$** | **Total** |
| **Highway Vehicles** | **1,508.6** | **3.7** | **45.1** | **1,557.4** |
| Park-Owned Operations | 227.8 | 0.3 | 5.5 | 233.5 |
| *Shuttle Buses* | *176.2* | *0.2* | *4.4* | *180.9* |
| *Other Park Vehicles* | *51.5* | *0.1* | *1.0* | *52.6* |
| Park-Leased Operations | 85.2 | 0.2 | 2.4 | 87.7 |
| *GSA Vehicles* | *76.2* | *0.2* | *2.1* | *78.4* |
| *Acme Vehicles* | *9.0* | *+* | *0.2* | *9.3* |
| Xanterra Operations | 23.1 | 0.1 | 0.7 | 23.9 |
| Visitors | 1,172.5 | 3.2 | 36.6 | 1,212.2 |
| **Nonroad Vehicles/Equipment** | **9.6** | **+** | **0.1** | **9.7** |
| Park-Owned Operations | 9.5 | + | 0.1 | 9.6 |
| Park-Leased Operations | NA | NA | NA | NA |
| Xanterra Operations | 0.1 | + | + | 0.1 |
| Visitors | NA | NA | NA | NA |
| **TOTAL** | **1,518.2** | **3.7** | **45.2** | **1,567.1** |
| **Park-Owned Operations** | **237.3** | **0.3** | **5.5** | **243.2** |
| **Park-Leased Operations** | **85.2** | **0.2** | **2.4** | **87.7** |
| **Xanterra Operations** | **23.2** | **0.1** | **0.7** | **24.0** |
| **Visitors** | **1,172.5** | **3.2** | **36.6** | **1,212.2** |

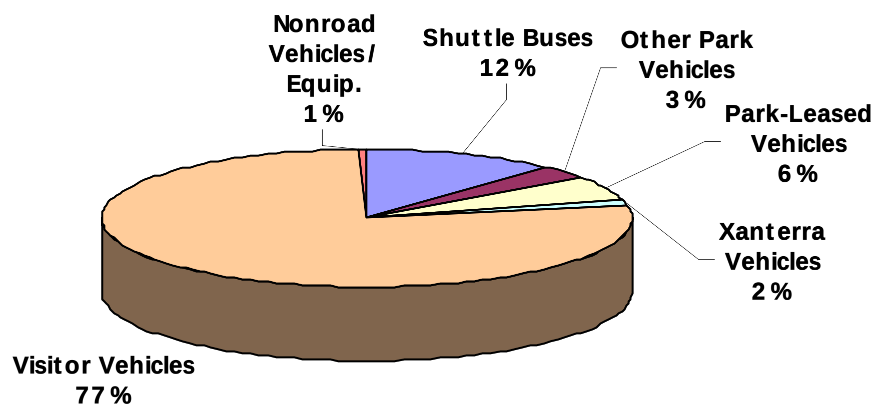
Note: Totals may not sum due to independent rounding.
NA = Not Applicable. + Does not exceed 0.05 MTCE.

As shown in Figure 3.1, visitor activities were responsible for the vast majority (77 percent or about 1,212 MTCE) of total GHG emissions from mobile sources. The high contribution of GHGs from visitors is largely due to the number of VMT by visitors in the park. Although the average number of miles traveled by park and concessionaire vehicles was higher than the miles traveled by visitor vehicles, visitor VMT represented 87 percent of all miles driven in the park. This is because the VMT differences were overshadowed by the high number of visitor vehicles (938 thousand) as compared to park and concessionaire vehicles (about 134 in use in 2002). Collectively, park, concessionaire, and visitor vehicles traveled over 10.8 million miles in the park in 2002. Table B-3 in Appendix B presents VMT estimates by fuel and vehicle type due to park, concessionaire, and visitor activities.

Next to visitor vehicle emissions, most of the remaining mobile source emissions (23 percent) came from park-owned and leased vehicles. Park-owned vehicles (shuttle buses and other vehicles) contributed 15 percent of the park's total mobile source emissions, and park-leased vehicles contributed 6 percent. Emissions from the visitor shuttle buses accounted for the majority (77 percent) of park-owned highway vehicle driving. Although the concessionaire, Parks Transportation, Inc., operates the visitor shuttle bus system, emissions for these buses are included under park operations because the park implemented this program and require visitors to use it. Most emissions from park-leased vehicles (89 percent) came from vehicles leased from GSA, which is consistent with GSA's contribution to Zion's VMT from park-leased vehicles (also 89 percent). GSA-leased vehicles were driven approximately the same amount as Acme-leased vehicles; however, the park leased 61 vehicles from GSA, compared to 7 vehicles from Acme, causing VMT from GSA-leased vehicles to be much higher than that from Acme-leased vehicles. Xanterra's vehicles were responsible for just 2 percent of the park's mobile source emissions. Vehicle use data for park residents were not available to allow for estimation of mobile source emissions.

Nonroad sources comprised less than 1 percent of Zion's mobile emissions. Nonroad sources include vehicles and equipment such as tractors, lawn mowers, and snowmobiles. Zion's nonroad source emissions were almost entirely from park-owned equipment (99 percent), with the balance coming from equipment owned by Xanterra.

**Figure 3.1: Mobile Combustion Emissions by Operation**




## 3.2 Methodology and Data Sources

### 3.2.1 Highway Vehicles

In order to estimate emissions from mobile highway sources, information on vehicle type, fuel use, VMT, and vehicle vintage was requested from the park and from Xanterra for owned and leased vehicles. The sources of these data are presented in Table 3.2.

The Intergovernmental Panel on Climate Change (IPCC) provides guidance on the methodologies for estimating GHG emissions from mobile combustion (1997). The methodology used to estimate $CO_2$ is based on fuel consumption, since the amount of $CO_2$ is primarily dependent on the carbon content of gasoline. Because park and Xanterra personnel provided more complete data on VMT than fuel use for their vehicles, fuel consumption was estimated by dividing VMT estimates (discussed below) by average fuel economy in units of miles per gallon (mpg). This was done for each vehicle type and operation. Xanterra supplied average mpg values for each of their vehicles (Stewart 2004), as did Parks Transportation, Inc. for the propane-fueled shuttle buses[16] (Scott 2004). Fuel use for the remaining vehicles (other park-owned, leased, and visitor vehicles) was estimated using the U.S. average fuel economy by vehicle type (FHWA 2003).

Once motor gasoline, diesel, and propane fuel consumption was estimated for park-owned (shuttle buses and other vehicles), park-leased (GSA and Acme), Xanterra, and visitor vehicles, it was converted to energy units (i.e., British thermal units, Btu) and multiplied by fuel-specific carbon coefficients. The resulting total carbon content for each fuel was then multiplied by the fraction of carbon assumed to be oxidized to the atmosphere (99 percent). See Table B-1 for heat contents, carbon contents, oxidation factors, and Table B-2 for U.S. average fuel economy.

Unlike $CO_2$, emissions of $CH_4$ and $N_2O$ are dependent on vehicle type and emission control technology. The methodology used to estimate these emissions is similar to the methodology described in detail in *Gateway National Recreation Area's Criteria Air Pollutant and Greenhouse Gas Emissions Inventory* (ICF 2003) and carried out in *Glacier National Park's Greenhouse Gas Emissions Inventory* (ICF 2004). As in those park inventories, some data gaps were filled using national average data taken from EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (2004). The method used to estimate emissions from highway vehicles is consistent with international guidelines, as set forth in IPCC's *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (1997). An explanation of the differences between the Gateway approach and the method implemented for Zion is provided below:

<u>Age Distribution of Park and Concessionaire Fleets</u>: Zion and Xanterra provided model years for most of their vehicles; therefore, park and concessionaire data, not national data, were used to determine the age distribution of the vehicle fleets. Model years were used to discern the type of emissions control technology used in each vehicle. For vehicles that were missing model year data, control technologies were assigned based on the following assumptions:

- *Park-owned Light-Duty Gas Trucks (LDGT).* LDGTs without assigned model years were assumed to have a Tier-1 compliant control technology ($T_1$). $T_1$ is the most common type for model years 1995-1999 (and common for years preceding and following this range), which appears to be the general age of most other vehicles in this category.
- *Park-owned Heavy-Duty Gas Vehicles (HDGV).* HDGVs without assigned model years were assumed to have non-catalyst (N) control technology because that is the most prevalent type for model years 1984-1995.
- *Park-owned Heavy-Duty Diesel Vehicles (HDDV).* The park's utility van was assumed to have advanced (A) control technology because the other HDDV tended to be of newer model years. The park's dump truck was assumed to have moderate (M) control technology since other similar vehicles were of older model years.
- *GSA-Leased Vehicles.* For LDDTs leased from GSA, vehicles with unassigned model years were assigned (A) control technology, since all LDDT since 1996 have been designed with that control technology, and, because they are leased, the trucks are probably of a more recent model year.
- *Acme-Leased Vehicles.* For the LDGVs and LDGTs leased from Acme, vehicles were assigned model years 1998-2002 based on the frequency of model years of GSA-leased vehicles.

16 The propane-fueled visitor shuttle buses at Zion average 3.1 mpg (Scott 2004).

- *Xanterra-owned HDGV.* Since most of Xanterra's vehicles were of model years ranging from the late 1990s to 2002, their HDGVs were assumed to be $T_1$, the most common control technology for HDGV during those model years.

Visitor VMT: The Center for Environmental Research and Technology completed a mobile sources criteria air pollutant inventory for Zion in 2000 (CE-CERT 2003a). This report provided estimates of average visitor VMT for summer months as well as for winter months; these estimates were used to calculate 2000 VMT assuming 7 summer months and 5 winter months. This estimate was then scaled for the year 2002 based on the ratio of 2002 visitation to visitation in 2000.[17] All visitor vehicles were assumed to travel the same distance, irrespective of model year. Total visitor VMT was distributed among vehicle types based on CE-CERT (2003a), as shown in Table B-6. The percentages provided in CE-CERT (2003a) added up to only 99.9 percent, and thus needed to be adjusted slightly. VMT for each vehicle type was then distributed among different model years based on the percentages shown in Table B-7, from CE-CERT (2003b).

Visitor VMT from tour buses was provided by CE-CERT (2003a) and was distributed among model years based on the VMT distribution for other HDDV.

### 3.2.2 Nonroad Sources

Fuel use data are used to estimate $CO_2$, $CH_4$, and $N_2O$ emissions from nonroad vehicles and equipment. The sources of data on fuel consumption for nonroad vehicles and equipment are presented in Table 3.2. To estimate $CO_2$ emissions from nonroad sources, the same methodology described above for highway vehicles was used. The methodology for estimating $CH_4$ and $N_2O$ emissions is similar to that described in ICF (2003), which employs the methods and some default data used to estimate national emissions for EPA (2004) and is consistent with international guidelines, set forth by the IPCC (1997).

Please refer to Appendix B (Tables B-4 and B-5) for the emission factors used to calculate $CH_4$ and $N_2O$ emissions for all mobile sources.

**Table 3.2: Data Sources for Estimation of GHG Emissions from Mobile Combustion**

| Source | Data Source |
|---|---|
| **Activity Data** | |
| Zion park-owned and leased vehicle fuel use, vehicle type data, and miles traveled data; visitor vehicle miles traveled estimates | Allred and Flatray 2004, Lammert 2004 |
| Zion park-owned nonroad vehicle/equipment fuel use | Ballard 2004, Allred and Flatray 2004 |
| Zion park-owned visitor shuttle bus miles traveled and mpg | Scott 2004 |
| Xanterra vehicle and nonroad fuel use, vehicle type, and miles traveled data | Stewart 2004 |
| Visitor vehicle miles traveled | CE-CERT 2003a |
| Number of visitor vehicles | Allred and Flatray 2004 |
| Vehicle age distribution used for park visitor vehicles | CE-CERT 2003b |
| Visitor vehicle type | CE-CERT 2003a |

[17] This methodology may slightly overstate visitor VMT because the visitor shuttle system became operational in May of 2000, but was operational for all of the summer months (including April) in 2002.

| **Source** | **Data Source** |
|---|---|
| **Factors** | |
| Heat contents, carbon contents, and fraction oxidized factors | EPA 2004 |
| $CH_4$ and $N_2O$ emission factors for highway vehicles | EPA 2004 |
| $CH_4$ and $N_2O$ emission factors for nonroad vehicles | IPCC 1997 |
| Density values for diesel and gasoline | EPA 2004 |
| U.S. average fuel economy | FHWA 2003 |

# 4 WASTE DISPOSAL

The greatest source of greenhouse gas (GHG) emissions resulting from municipal solid waste (MSW) disposal is landfill methane ($CH_4$). $CH_4$ is emitted as organic materials (i.e., materials containing carbon) decompose in an oxygen-deprived (anaerobic) environment. Estimates of landfill $CH_4$ emissions for Zion are based on the amount of MSW that was disposed in garbage receptacles within park boundaries and subsequently sent to a landfill. The waste in these receptacles was generated by a combination of park employees, residents, concessionaires, and visitors; however, only the park and its lodging concessionaire, Xanterra, handled the waste disposal. As a result, emissions from solid waste disposal at Zion by park employees, residents, and visitors were attributed to the park, while disposal emissions for Xanterra employees and Zion Lodge visitors were attributed to Xanterra.

Although emissions from the landfilling of MSW generated at the park actually occur at the landfill site, and therefore take place outside park boundaries, they are included in Zion's GHG inventory because the waste-generating activities underway *within* the park are indirectly responsible for these emissions. Should the park or Xanterra continue to expand waste reduction efforts, these emissions could be reduced. The park and its concessionaires already recycle many materials, including glass, cardboard, aluminum, paper, plastic, and batteries. In 2002, the recycling of glass, cardboard,[18] aluminum, plastic and steel cans, and mixed and white paper by the park and Xanterra reduced $CH_4$ emissions by about 42 metric tons of carbon equivalent (MTCE), which is roughly equivalent to removing 32 cars from the road each year. These efforts also saved 1,220 million British thermal units (Btu) of energy, which equates to about 210 barrels of oil or 9,780 gallons of gasoline.[19] Expanding on these recycling efforts even further and reducing waste in other ways could significantly lower Zion's waste-related GHG emissions (see Box 4.1).

The sections that follow discuss the results of our analysis of emissions from MSW disposal and an overview of the methodology and data sources used in the calculations.

**Box 4.1: Reducing GHGs by Reducing Waste**

Zion can reduce its GHG emissions and save energy simply by sending less waste to landfills. By increasing the fraction of park wastes that are recycled, Zion can reduce emissions from landfills and reduce emissions that occur "upstream" as virgin raw materials are displaced by recycled inputs. Zion can further reduce waste generation and emissions by consuming less material in the first place. One option might be to evaluate purchasing policies and to attempt to purchase items in bulk to reduce the overall need for packaging materials. Office staff may also reduce the amount of paper they consume by using double-sided printers and copiers.

If Zion's 2002 wastes were reduced by one third, its emissions for that year would have been about 2 MTCE lower. However, since waste produces $CH_4$ emissions over a 30-year period, reducing waste disposal has a much greater impact in the long run. Had Zion's waste disposal been reduced by one third for each of the past 30 years, its 2002 waste-related emissions would have been 73 MTCE lower, which is equivalent to removing 53 passenger cars from the road, or saving 2 acres of forest from deforestation. Efforts to reduce Zion's waste disposal now will have similar long-term benefits.

## 4.1 RESULTS

The emissions attributed to the waste sector for Zion are solely from the $CH_4$ generated by the anaerobic decomposition of organic wastes in landfills.[20] In 2002, Zion National Park

[18] Cardboard comprised 61 percent of the park and Xanterra's recyclables in 2002.
[19] Emissions reductions, energy savings, and equivalencies estimated using recycling tonnage data from the Park (Starling 2004 and Stewart 2004) and EPA's WAste Reduction Model (WARM), available online at http://yosemite.epa.gov/oar/globalwarming.nsf/WARM. Note that these reductions reflect emissions reduced throughout the material life-cycle and are therefore not directly comparable to emissions from waste sector activities alone.
[20] There are other GHG emissions associated with MSW disposal, including carbon dioxide and nitrous oxide emissions from incineration. Zion incinerates tree limbs and brush in the park. Emission estimates for burning of this biogenic material is included under prescribed burning in the forestry chapter.

emitted approximately 220 MTCE from MSW disposal. This quantity represents the largest share of non-forestry-related $CH_4$ emissions in the park (95 percent), and 33 percent of the park's overall $CH_4$ emissions (including forest burning).

As shown in Table 4.1, the majority of Zion's waste emissions are attributed to waste collected in park receptacles, comprising 64 percent (140 MTCE) of the park's emissions from this source. The remaining emissions (80 MTCE) are attributed to waste managed by Xanterra. Possible explanations for why Zion generated more waste than Xanterra include the larger number of park employees (roughly 1.5 times greater than the average year-round number of Xanterra employees), the inclusion of resident waste in the park's disposal, and a greater share of visitor-generated waste being disposed in the park's (rather than Xanterra's) receptacles.

**Table 4.1: Summary of GHG Emissions from MSW Disposal**

| Source | $CH_4$ Emissions (MTCE) |
|---|---|
| Waste Disposed by Park | 140.1 |
| Waste Disposed by Xanterra | 80.0 |
| **TOTAL** | **220.1** |

## 4.2 METHODOLOGY AND DATA SOURCES

In order to estimate emissions from MSW disposal, the park and Xanterra were asked to provide the mass of MSW disposed annually and the name of the landfill where the waste is ultimately disposed (see Table C-1 in Appendix C). The sources of these data are presented in Table 4.2.

Emissions from MSW were based on estimates of waste disposal. The methodology used is similar to that described in *Gateway National Recreation Area's Criteria Air Pollutant and Greenhouse Gas Emissions Inventory* (ICF 2003) and is consistent with EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (2004) and international estimation guidelines, as set forth in IPCC's *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (1997). An explanation of the differences between the Gateway approach and the method implemented for Zion is provided below:

Park Population: Visitor populations for the last 30 years were estimated by obtaining visitor data from NPS (2004) for 1994-2002, and then backcasting visitor population using a linear regression. Data on full-time and seasonal employees were obtained from Eddie Lopez (2004) for Zion, and Brian Stewart (2004) for Xanterra; employee population was assumed constant during the 30-year timeframe. Visitor and employee populations were used to estimate average park population. Visitor populations include every visitor that enters the park, regardless of length of stay (usually only a few days); meanwhile employee populations reflect the number of employees employed throughout the year (for full-time employees) or during the 7-month peak season (for seasonal employees). Therefore, population estimates were adjusted to ensure that visitor and employee waste contributions were properly accounted for in the average daily park population.

The sum of park employee plus visitor population was used to calculate per capita landfilling tonnages for the park, and the sum of Xanterra population and visitor population was used to estimate per capita landfilling tonnages for Xanterra. These per capita estimates were then used to backcast disposal for the years prior to 2002 based on population.

Destination Landfills: All waste was assumed to go to the Washington County Solid Waste Landfill, based on data received from the park and concessionaire contacts. This landfill began accepting waste in

1978. Since waste produces $CH_4$ over a 30-year period, waste disposed between 1972 and 1977 must have gone to a different landfill. This 'other' landfill is believed to be the landfill in St. George County, which closed in 1981. However, data regarding waste-in-place and the existence of a $CH_4$ collection system at the St. George Landfill were not available; for calculation purposes, all waste from Zion for the full 30 year period was assigned to the Washington County Landfill.

The Washington County Landfill is considered a large, arid landfill (EPA 2003a, EPA 2003b).[21] This designation corresponds to the regression equations used to calculate landfill $CH_4$ generation as provided in EPA (1999). Because information on the presence of $CH_4$ collection systems at the landfill could not be located[22] and it is believed that such systems do not exist at the Washington County Landfill. Waste-in-place, $CH_4$ generation, and other characteristics for the Washington County Landfill are provided in Table C-2. Table C-3 presents the equations used to estimate $CH_4$ generation.

**Table 4.2: Data Sources for Estimation of $CH_4$ Emissions from Landfilled Waste**

| **Source** | **Data Source** |
|---|---|
| **Activity Data** | |
| Zion Park waste disposal data | Starling 2004, Louie 2004 |
| Concessionaire waste disposal data | Stewart 2004 |
| Number of park employees | Lopez 2004 |
| Number of concessionaire employees | Stewart 2004 |
| Number of visitors for 1994-2002 | NPS 2004 |
| Destination landfill characteristics | EPA 2003a |
| **Factors** | |
| $CH_4$ generation equations | EPA 2003b |

[21] Washington County Landfill qualified as (1) arid because it is located in a state with average annual rainfall of less than 25 inches, and (2) large because it contains over 1.1 million tons of waste in place, based on the definitions presented in EPA 2003b.
[22] While EPA 2003a reports data on Washington County Landfill, it does not provide any information on $CH_4$ collection systems at that particular landfill. In addition, officials at the landfill could not provide information on the presence of such systems.

# 5 FORESTS

Forests accumulate and emit carbon as organic material grows and dies. When carbon is emitted, it is emitted in the form of carbon dioxide ($CO_2$). Methane ($CH_4$), and nitrous oxide ($N_2O$) are emitted when organic materials in the forest are burned. During photosynthesis, trees incorporate carbon into living tissues. This process is called carbon sequestration, and it reduces the rate at which $CO_2$ accumulates in the atmosphere. Fast-growing trees sequester carbon at a faster rate than slow-growing trees or trees that have already matured. When forests later decay, burn, or are harvested, $CO_2$, $CH_4$, and $N_2O$ are emitted to the atmosphere where they act as GHGs.

Together, the emissions and sequestration of carbon in Zion National Park comprise its net forest-related carbon "flux." The carbon flux varies greatly in forested ecosystems as it is sensitive to land management, climate variability, and natural processes. Subtle changes in these variables can alter an ecosystem's condition from a steady state (i.e., one that is neither accumulating nor losing carbon on the whole), to a net source (i.e., an ecosystem that emits more carbon than it stores), or a net sink (i.e., an ecosystem that stores more carbon than it emits). Although these changes often only represent a small change in total forest carbon storage, their magnitude may be important when considering the park's net GHG emissions, as even small changes to such a large carbon reservoir can produce fluxes exceeding those from other GHG sources.

The sections that follow discuss the results of this analysis of the net flux from Zion's forests, $CH_4$ and $N_2O$ emissions from burning, and provide an overview of the methodology and data sources used in the calculations.

## 5.1 RESULTS

In 2002, forestry activities in Zion resulted in a net sequestration of about 2,140 metric tons of carbon equivalent (MTCE), representing an offset of approximately 94 percent of Zion's total GHG emissions. This value represents the balance of sequestration from forest growth and of emissions resulting from forest fires and burning and thinning activities within park boundaries. Zion's forests were a net sink of $CO_2$, which indicates that forest growth outpaced burning, clearing, and decay.[23] Zion's forests were a net $CO_2$ sink on the order of 2,680 MTCE, while fires contributed 535 MTCE of $CH_4$ and $N_2O$ to overall emissions. Zion's net carbon flux of -2,680 MTCE is significantly smaller than that estimated for Glacier National Park's (–78,530 MTCE) (ICF 2004). This is because Zion's landscape includes far fewer acres of forest, and the forest types that are present did not grow as rapidly as Glacier's dense forests. Zion's carbon flux makes up less than 1 percent of the nation's forest carbon flux, which was estimated at -105 million MTCE[24] in 2002 (EPA 2004).

Table 5.1 shows the park's estimated carbon flux resulting from the growth, decay, burning, and thinning of the standing forests, and non-$CO_2$ emissions from burning activities.

[23] Forest flux is dependent on climate, ecosystem health, extent of forest burning, etc. and is highly variable year to year. It is possible for a forest to be a net sink in one year and a net emitter the following year. However, in the long term, healthy, natural forests are generally net sinks or in a steady flux state (i.e., neither a sink nor a source).

[24] Excludes harvested wood products.

**Table 5.1: GHG Emissions and Carbon Flux from Standing Forests, Burning, and Thinning**

| Source Category | Emissions/Sequestration (MTCE) |
|---|---|
| Forest ($CO_2$ Flux) [a] | (2,679) |
| Burning ($CH_4$ and $N_2O$ only)[b] | 535 |
| **TOTAL** | **(2,144)** |

Note: Parentheses indicate net carbon sequestration
[a] Represents $CO_2$ flux.
[b] Includes $CH_4$ and $N_2O$ from burning, but not $CO_2$. $CO_2$ fluxes from burning and thinning are inherently captured in the standing forest flux value.

Zion has a fire management plan that includes provisions for burning and thinning its forest as part of an overall goal of maintaining a healthy and natural ecosystem. While these practices lead to short-term emissions, it is believed that they reduce the parks vulnerability to catastrophic future fire events and associated emissions. Estimates of emissions calculated for both burning and thinning are shown in Table 5.2. Note that these $CO_2$ estimates are captured in the net $CO_2$ flux value presented above. The table below presents two separate sets of estimates for burning, which reflect the results of two different methodologies, as described in Section 5.2.2.1. Both sets of results are presented here for comparison purposes only; however, because the first approach (i.e., Intergovernmental Panel on Climate Change (IPCC) method) allowed for the estimation of $N_2O$—not included in the second approach—and because the methodologies used to estimate emissions from other sources in this inventory maintain consistency with IPCC, the IPCC emission results are reflected in Zion's totals. Thinning and burning resulted in emissions of $CO_2$, $CH_4$, and $N_2O$ totaling roughly 5,270 metric ton of carbon equivalent (MTCE). Of that total, the $CH_4$ and $N_2O$ emissions of 435 and 99 MTCE, respectively, account for the non-$CO_2$ burning emissions reported above (i.e., 535 MTCE).

**Table 5.2: Emissions from Burning and Thinning**

| Source Category | Emissions (MTCE) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| Burning[a] | 4,467 | 435 | 99 | **5,002** |
| Burning[b] | 3,763 | 797 | NA[c] | **4,560** |
| Thinning | 269 | NA | NA | **269** |
| **TOTAL[d]** | **4,736** | **435** | **99** | **5,271** |

[a]Emissions from burning calculated with the IPCC Method (See Section 5.2.2.1.).
[b]Emissions from burning calculated with the First Order Fire Effects Model (See Section 5.2.2.2.).
[c]FOFEM does not provide $N_2O$ emission outputs.
[d]The total presented here reflects thinning emissions and burning emissions estimated using the IPCC method.

Sequestration in Zion's forests is attributed to the storage of carbon in various interrelated carbon storage pools. Carbon stocks are a measure of the net amount of carbon that has been sequestered from the atmosphere and incorporated into living biomass over the forest's entire lifetime. Tracking carbon stocks is important because it allows us to calculate forest flux by finding the change in carbon stocks from one year to another. Table 5.3 presents these pools and their corresponding carbon stock in Zion forests. In 2002, carbon stocks in Zion forests totaled 8.66 million MTCE. The majority of this carbon was stored in forest soils (44 percent) and living and standing dead trees (36 percent).

**Table 5.3: Forest Carbon Stocks**

| Forest Carbon Pool | Carbon Stock (million MTCE) |
|---|---|
| Trees (Living + Standing Dead) | 3,099 |
| Soils | 3,786 |
| Forest Floor | 964 |
| Understory Vegetation | 213 |
| Down Dead Wood | 597 |
| **TOTAL** | **8,659** |

Table 5.4 presents the proportion of carbon stored in each carbon pool (standing tree, soil, forest floor, understory, and down dead wood) by forest type at Zion. This table is used to provide a characterization of the forest, showing which species store the greatest amount of carbon within Zion's forests. At Zion, Hardwoods (including chaparral) and Ponderosa pine have the largest effect on carbon storage. These forest types stored an average of about 45 and 25 percent, respectively, of carbon across the various pools (as shown in Table 5.4). Those species that store the most carbon could have the greatest effect upon carbon flux if they were to be removed from the forest. A species may contribute a large carbon stock to a forest because (a) the species covers a large area within the forest, and/or (b) the species has a high carbon density.

**Table 5.4: Forest Carbon Stocks by Forest Type**

| Forest Type | Tree Carbon | Soil Carbon | Forest Floor | Understory | Down Dead Wood | Average |
|---|---|---|---|---|---|---|
| Ponderosa pine | 27.7% | 24.1% | 27.3% | 15.3% | 28.8% | 24.7% |
| Fir-spruce | 7.2% | 7.2% | 7.6% | 2.1% | 6.0% | 6.0% |
| Hardwoods | 48.5% | 35.5% | 17.3% | 60.2% | 62.2% | 44.7% |
| Other forest types | 3.9% | 5.2% | 6.4% | 5.6% | 0.6% | 4.3% |
| Pinyon-juniper | 12.7% | 28.1% | 41.3% | 16.7% | 2.4% | 20.2% |
| **TOTAL** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

Note: Totals may not sum due to independent rounding.

In 1993, the Utah Department of Environmental Quality found that the forests in southern Utah were net GHG emitters (Utah DEQ 1993). However, neither Zion, which is categorized in this evaluation as a sink, nor other regional National Parks seem to be explicitly addressed by this evaluation. This discrepancy in GHG emission values is likely due to different land management practices at Zion compared with surrounding lands under other management regimes, such as BLM land subject to grazing or private lands subject to road building or other construction. In addition, a great deal of uncertainty is inherent in forest carbon flux estimates at various levels.

## 5.2 Methodology and Data Sources

This section first presents the methodology and data sources used to estimate forest carbon flux and the carbon stocks, and then presents the methodology and data sources used for the separate burning and thinning calculations. Overall data sources are presented at the end of this chapter in Table 5.7.

### 5.2.1 Forest Carbon Flux

To estimate the carbon stored in Zion's forests and its average annual change, or flux, U.S. Forest Service measurements (Birdsey and Lewis 2002) of forest carbon storage and flux for the state of Utah were combined with Zion park-level area data for each forest type (Bradybaugh, et al. 2004). A more detailed description of the methods used to estimate average annual flux and carbon stocks in Zion's forests are provided below.

Average Annual Flux in Zion's Forests: Birdsey and Lewis (2002) provide RPA (Resources Planning Act) data by tree type in Utah. The data include forest area by tree type as well as total carbon stock by tree type for the years 1987, 1992, and 1997. For each of these years, the carbon stocks (in MTCE) were divided by forest area (in hectares) for each forest type. The resulting carbon density estimates for the year 1987 were subtracted from the 1997 estimates and divided by the number of intervening years (10) to arrive at the average annual carbon change (MTCE/hectare). These estimates of average annual fluxes for each forest type in Utah were then multiplied by Zion area data, which were provided by Bradybaugh, et al. (2004) for the major forest types in the park (see Table D-1 in Appendix D), to determine the average annual forest flux for each tree type in Zion. The sum of these fluxes equaled the total average annual flux for Zion's forests. Table 5.5 presents Utah's average annual flux, the adjusted Zion forest area, and the resulting average annual flux for Zion by forest type.

It was necessary to apply certain adjustments to the forest types used in these calculations due to inconsistencies between some of the forest data for Utah (Birdsey and Lewis 2002) and Zion (Bradybaugh, et al. 2004). The Birdsey and Lewis RPA data show that non-stocked and chaparral forest areas drop below 1,000 acres by 1997, while Zion data show that these forest types are still present in 2002. Because of this discrepancy and because non-stocked forests are no more than 10 percent vegetated, changes in carbon stocks on those lands were not included in this appraisal. In other words, the non-stocked forest was assumed to be non-forested land for purposes of this inventory. Due to a vagary in the Birdsey and Lewis RPA dataset, chaparral within Zion was reclassified for the purposes of this evaluation as Hardwood area, because it is often composed primarily of Gambel oak (Bastian 2004). Finally, the Fir-spruce-Douglas fir area provided by Zion does not correspond to any single forest type specified within the RPA system; the area was assumed to be Fir-spruce forest as recommended by Bastian (2004).

**Table 5.5: Adjusted Forest Area, Average Annual Flux per Hectare by Forest Type, and Average Annual Flux for Forest Types**

| Forest Type | Avg Annual Flux for Utah (MTCE/ha)[a] | Adjusted Zion Area (ha) | Avg Annual Flux for Zion (MTCE) |
|---|---|---|---|
| Ponderosa pine | -0.33 | 12,175 | -4,040 |
| Fir-spruce | 1.14 | 1,849 | 2,108 |
| Hardwoods | 0.38 | 15,853 | 6,076 |
| Other forest types | -0.50 | 2,049 | -1,033 |
| Pinyon-juniper | -0.02 | 17,728 | -433 |
| **Total** | | **49,654** | **2,679** |

[a] Source: Birdsey and Lewis 2002.

Carbon Stocks in Zion's Forests: The total carbon stock of Zion was estimated by (1) calculating the weighted average carbon density for each forest type within Utah (using RPA data), and (2) multiplying the weighted carbon density of Utah's forests by Zion's forest area. Total stock for Zion was estimated to be 8,660 million MTCE.

Carbon stocks were then calculated separately for the following carbon pools: trees, soils, forest floor, understory, and down dead wood. Because the RPA data do not break down carbon densities by pool, the initial stock calculations were based on regional factors provided for each forest pool and forest type provided by EPA (2003) (see Table D-2). Western U.S. carbon density factors specific to tree, soil, and forest floor carbon pools and forest type from EPA 2003 were multiplied by the area of each forest type to estimate tree, soil, and forest floor carbon stocks. The Southern Rocky Mountain region ratios of understory wood to live tree carbon and down dead wood to live tree carbon (EPA 2003) were multiplied by the live tree carbon stocks to estimate understory and down dead wood carbon stocks. The resulting distribution of carbon across pools (see Column 2 in Table 5.6) was then used to apportion the total carbon stock, as calculated above using the RPA weighted average forest carbon density in Utah, across the carbon pools in Zion (see Column 3 in Table 5.6).

**Table 5.6: Carbon Stock Calculations**

| Forest Carbon Pool | Carbon Stock based on Regional Factors (MTCE) | Carbon Stock Apportioned to Reflect Weighted Average Utah Forest Carbon Density (MTCE) |
|---|---|---|
| Trees (Living + Standing Dead) | 2,909,336 | 3,099,089 |
| Soils | 3,554,388 | 3,786,212 |
| Forest Floor | 905,092 | 964,124 |
| Understory | 199,596 | 212,614 |
| Down Dead Wood | 560,141 | 596,675 |
| **TOTAL** | **8,128,553** | **8,658,713** |

Note: Totals may not sum due to independent rounding.

### 5.2.2 Burning and Thinning

Zion maintains an active prescribed burning program in order to "reduce hazardous fuel loads near developed areas, manage landscapes, restore natural woodlands and for research purposes" (NPS 2004). Additionally, wildfires also occur in Zion's landscapes. The burning of forests results in emissions of $CO_2$, $CH_4$, and $N_2O$, regardless of the initial cause or management use of the fire. The harvesting or thinning of forests results in a net carbon loss as the removed wood is burned or decomposes.

Two separate methods were used to calculate $CO_2$, $CH_4$, and $N_2O$ emissions from forest fires in Zion: (1) the Intergovernmental Panel on Climate Change (IPCC) method, which calculates $CO_2$, $CH_4$, and $N_2O$ emissions; and (2) the First Order Fire Effects Model (FOFEM), which estimates $CO_2$ and $CH_4$ emissions in addition to criteria air pollutants. Thinning was estimated separately according to the IPCC default methods for forest removals. Each of these calculations is described separately below; however, it is important to note that only the $CH_4$ and $N_2O$ emissions from burning using the IPCC method are included in the emission results for this inventory. $CO_2$ emissions from burning and thinning are inherently captured above in the estimation of carbon flux; alternate methods were utilized for comparison purposes and are presented here as background information.

#### 5.2.2.1 IPCC Method and Data Sources for Calculating Emissions from Forest Fires

The IPCC provides guidance for estimating GHG emissions from both wildfires and prescribed burn forest fires (IPCC 2003). $CO_2$, $CH_4$, and $N_2O$ emissions were estimated using the equation in Box 5.1.

Emissions depend on the area that is burned, the density of biomass on that area, the combustion efficiency of the fire, and the GHG-specific emission factor associated with the amount of forest biomass that has been consumed. These components are described below.

**Box 5.1: Estimation of GHGs Directly Released in Fires**

*Emission of GHG Gases from Forest Fires (MT) = Area Burned (ha) x Biomass Density (kg d.m. / ha) x Combustion Efficiency x Emission Factor for $CO_2$, $CH_4$, or $N_2O$ (g / kg d.m.) x $10^{-6}$*

Source: IPCC 2003.
Note: d.m. = dry matter.

Area Burned: Data on the area of forests burned in Zion in 2002 were gathered from Bradybaugh et al. (2004) (see Table D-3 in Appendix D). One of the burning projects, a prescribed grass burn, was not included in the estimates because grass burning involves a different methodology and the emission source was deemed too small to quantify given resources available.

Biomass Density: Biomass density refers to the amount of living material in the forests that occupies a given amount of land. Ponderosa pine, for example, contains more living matter on an acre than does mountain brush. This difference in the amount of aboveground biomass in different land cover types means that during fires, different amounts of material will burn in different types of forests. The biomass densities for forest types burned in Zion are provided in Table D-4.

Combustion Efficiency: The IPCC default combustion efficiency factor for "other" temperate forests of 0.45 was used for these calculations. This value indicates that 45 percent of the materials exposed to the fires were burned to the degree that they were converted into GHGs. While different types of fires may have inherently different combustion efficiencies (e.g., a wild crown fire will burn a greater proportion of the biomass it is exposed to than a low-temperature prescribed fire), the default value attempts to average out these differences for application to a wide range of potential burn-types.

Emission Factor: Default IPCC (2003) emissions factors for the amount of burned material that is converted into $CO_2$, $CH_4$, and $N_2O$ for forest fires were used in calculating Zion's GHG emissions (see Table D-5).

Unit Conversion: Emissions of each of these gases were then converted to MTCE by multiplying the calculated emissions (in units of metric tons) by their respective Global Warming Potentials (GWPs) (also provided in Table D-5).

### 5.2.2.2 FOFEM Method for Calculating Emissions from Forest Fires

In addition to calculating burning emissions using the IPCC method described above, emissions of $CO_2$ and $CH_4$ were calculated using the FOFEM 5.2 model (Reinhardt and Keane 2003). FOFEM was developed at the Missoula Fire Sciences Lab to allow resource managers and planners to evaluate fire effects under a number of different circumstances. FOFEM is sensitive to the type of forest burned, the area, geographic region, season, fuel type (e.g., wood, litter, etc.), biomass density, moisture, and rotten wood. Data on the area burned by forest type from Zion (see Table D-3) were entered into the model. Where data were not available from the park, FOFEM's default data for the region were used. All data that were applied to the FOFEM analysis are provided in Table D-6 in Appendix D.

#### 5.2.2.3 Calculating Emissions from Forest Thinning

$CO_2$ emissions associated with forest thinning are captured in the estimate of $CO_2$ flux detailed in Section 5.2.1; however, they have been estimated separately here because Zion provided specific information on the forest acreage thinned in 2002. Harvested wood may be burned immediately, may decay over a long period of time, or may become part of a number of product pools (e.g., paper or construction materials), which persist over varying time periods. Because information regarding the actual fate of the wood from Zion's thinned forests was not available, for the purposes of this inventory, IPCC's conservative default methodology was used and forest area thinned was assumed to suffer immediate and complete GHG loss through decomposition (IPCC 2003). According to this method, emissions from thinning are calculated by multiplying the area of mountain brush thinned at Oak Creek in 2002 (as provided by Bradybaugh et al. (2004) in Table D-7 in Appendix D) by the average tree carbon density for chaparral (which has a carbon composition comparable to that of mountain brush, the land cover type found at Oak Creek). All carbon in the harvested wood was thereby assumed to return to the atmosphere in 2002. While this is unlikely to be the case, this methodology provides a conservative estimate of emissions related to thinning activities within Zion, as the carbon contained within the harvested wood would eventually return to the atmosphere over time.

**Table 5.7: Data Sources for Estimation of $CO_2$ Flux from Forests and $CH_4$ and $N_2O$ Emissions from Burning and Thinning**

| Source | Data Source |
|---|---|
| **Activity Data** | |
| Zion forest acreage data and forest management information | Bradybaugh et al. 2004 |
| Utah forest acreage and total carbon stock for 1987, 1992, and 1997 | Birdsey and Lewis 2002 |
| **Factors** | |
| Regional factors used in carbon stock calculations | EPA 2003 |
| Biomass density factors used to calculate emissions from forest fires | EPA 2003 |
| Emission factors used to calculate emissions from forest fires | IPCC 2003 |

# 6 REFERENCES

## 6.1 EXECUTIVE SUMMARY

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## 6.2 INTRODUCTION

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# APPENDIX A: STATIONARY COMBUSTION BACKGROUND TABLES

This appendix provides further background information on the activity data and factors used in the estimation of greenhouse gas (GHG) emissions from stationary combustion at Zion.

**Table A-1: Stationary Fuel Consumption at Zion National Park in 2002**

| Park Operation/Source | Fuel Consumption (energy units) |
|---|---|
| **Petroleum** | **(MMBtu)** |
| Park-Owned Operations | 1,810 |
| Residences | 991 |
| Xanterra Operations | 10,132 |
| Visitors | 4,447 |
| **Wood** | **(MJ)** |
| Park-Owned Operations | 4,357,813 |

Source: Starling 2004; Stewart 2004.

**Table A-2: Stationary Combustion Conversions and Emission Factors**

| Fuel Type | Heat Content | Carbon Content Coefficient (Tg C/QBtu) | Fraction Oxidized | Heating Value Conversion | Emission Factors (g gas/GJ) | |
|---|---|---|---|---|---|---|
| | | | | | $CH_4$ | $N_2O$ |
| **Petroleum** | **(MMBtu/barrel)** | | | | | |
| Distillate Fuel Oil | 5.825 | 19.95 | 99.0% | 95% | 10.0 | 0.6 |
| Propane | 3.836 | 17.20 | 99.5% | 95% | 10.0 | 0.6 |
| Lubricants | 6.065 | 20.24 | 99.0% | 95% | 10.0 | 0.6 |
| **Wood** | **(MJ/kg)** | | | | | |
| Wood | 16.6[a] | NA | NA | NA | 300.0 | 4.0 |

Sources: Heat contents, carbon contents, fraction oxidized factors, and heating value conversions from EPA 2004. Emission Factors and net calorific value for wood from IPCC 1997.
[a] Represents typical net calorific value for wood with 15 percent moisture.

**Table A-3: Electricity Purchased by Zion National Park in 2002**

| Source/Park Operation | Purchased Electricity (kWh) |
|---|---|
| Park-Owned Operations | 521,110 |
| Residences | 189,442 |
| Xanterra-Owned Operations | 1,141,298 |
| **TOTAL** | **1,851,850** |

Source: Starling 2004; Stewart 2004.

**Table A-4: Electricity Emission Factors**

| eGRID Subregion | eGRID Subregion Emission Factor (lbs $CO_2$ / MWh) [a] | Electricity Loss Factor [b] |
|---|---|---|
| WECC Great Basin [c] | 852.31 | 9% |

Source: Emission factor from EPA 2003. Electricity loss factor from EIA 2003.
[a] Emission factor selected for the eGRID subregion.
[b] Calculations account for an average electricity loss factor of 9 percent based on the average U.S. fraction lost during transmission and distribution.
[c] WECC Great Basin eGRID subregion fuel mix consists of approximately 58% hydro, 36% coal, 5% gas, 1% geothermal, <1% biomass, oil, and other fossil fuel.

# APPENDIX B: MOBILE COMBUSTION BACKGROUND TABLES

This appendix provides further background information on the activity data and factors used in the estimation of GHG emissions from mobile combustion at Zion.

**Table B-1: Mobile Combustion Conversions and Emission Factors for Estimating $CO_2$**

| Fuel Type | Heat Content (MMBtu/barrel) | Carbon Content Coefficient (Tg C/QBtu) | Fraction Oxidized |
|---|---|---|---|
| **Petroleum** | | | |
| Distillate Fuel Oil | 5.825 | 19.95 | 99.0% |
| Motor Gasoline | 5.253 | 19.34 | 99.0% |
| Propane | 3.836 | 17.20 | 99.5% |

Source: EPA 2004.

**Table B-2: U.S. Miles Per Gallon**

| | LDGV, LDDV | LDGT, LDDT | HDGV, HDDV (excluding Buses) [a] | Buses | MC |
|---|---|---|---|---|---|
| **MPG** | 22.13 | 17.62 | 5.84 | 6.90 | 50.00 |

Source: FHWA 2003.

Note: These categories include: LDGV: light-duty gas vehicles; LDDV: light-duty diesel vehicles; LDGT: light-duty gas truck; LDDT: light-duty diesel truck; HDGV: heavy-duty gas vehicle; HDDV: heavy-duty diesel vehicle (HDDV).

[a] Derived using weighted average of FHWA Other Single-unit Trucks and Combination Trucks.

**Table B-3: Vehicle Miles Traveled in Zion National Park in 2002**

| Source Category | Light-Duty Gasoline Vehicles (LDGV) | Light-Duty Gasoline Trucks (LDGT) | Heavy-Duty Gasoline Vehicles (HDGV) | Light-Duty Diesel Vehicles (LDDV) | Light-Duty Diesel Trucks (LDDT) | Heavy-Duty Diesel Vehicles (HDDV) | Motorcycles (MC) | Propane Vehicles (LPG) | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Park-Owned Vehicles | NA | 116,940 | 33,924 | NA | NA | 46,252 | NA | 349,541 | **546,656** |
| Park-Leased Vehicles | 98,901 | 537,546 | NA | NA | 9,132 | NA | NA | NA | **645,579** |
| Xanterra Vehicles | NA | 180,539 | 480 | NA | NA | NA | NA | NA | **181,019** |
| Visitor Vehicles | 6,587,401 | 2,283,507 | 75,177 | NA | 28,191 | 255,857 | 263,120 | NA | **9,493,254** |
| **Zion Park Total** | **6,686,302** | **3,118,532** | **109,581** | **NA** | **37,323** | **302,109** | **263,120** | **349,541** | **10,866,508** |

Source: Allred and Flatray 2004, Scott 2004, CE-CERT 2003a, Stewart 2004.
Note: NA = Not Applicable.

**Table B-4: $N_2O$ and $CH_4$ Emission Factors for Highway Vehicles**

| Vehicle Type / Control Technology | Emission Factors (g / mi) | |
|---|---|---|
| | $N_2O$ | $CH_4$ |
| **Gasoline Passenger Cars** | | |
| Low Emission Vehicles | 0.0283 | 0.0402 |
| EPA Tier 1[a] | 0.0463 | 0.0483 |
| EPA Tier 0[a] | 0.0816 | 0.0644 |
| Oxidation Catalyst | 0.0518 | 0.1127 |
| Non-Catalyst Control | 0.0166 | 0.1931 |
| Uncontrolled | 0.0166 | 0.2173 |
| **Gasoline Light-Duty Trucks** | | |
| Low Emission Vehicles | 0.0355 | 0.0483 |
| EPA Tier 1[a] | 0.0580 | 0.0563 |
| EPA Tier 0[a] | 0.1022 | 0.1127 |
| Oxidation Catalyst | 0.0649 | 0.1448 |
| Non-Catalyst Control | 0.0208 | 0.2253 |
| Uncontrolled | 0.0208 | 0.2173 |
| **Gasoline Heavy-Duty Vehicles** | | |
| Low Emission Vehicles | 0.1133 | 0.0708 |
| EPA Tier 1[a] | 0.1394 | 0.0966 |
| EPA Tier 0[a] | 0.2361 | 0.1207 |
| Oxidation Catalyst[b] | 0.1499 | 0.1448 |
| Non-Catalyst Control | 0.0480 | 0.2012 |
| Uncontrolled | 0.0480 | 0.4345 |
| **Diesel Passenger Cars** | | |
| Advanced | 0.0161 | 0.0161 |
| Moderate | 0.0161 | 0.0161 |
| Uncontrolled | 0.0161 | 0.0161 |
| **Diesel Light-Duty Trucks** | | |
| Advanced | 0.0322 | 0.0161 |
| Moderate | 0.0322 | 0.0161 |
| Uncontrolled | 0.0322 | 0.0161 |
| **Diesel Heavy-Duty Vehicles** | | |
| Advanced | 0.0483 | 0.0644 |
| Moderate | 0.0483 | 0.0805 |
| Uncontrolled | 0.0483 | 0.0966 |
| **Motorcycles** | | |
| Non-Catalyst Control | 0.0073 | 0.2092 |
| Uncontrolled | 0.0073 | 0.4184 |
| **LPG Buses** | 0.1502 | 0.1078 |

Source: EPA 2004.

**Table B-5: $N_2O$ and $CH_4$ Emission Factors for Nonroad Vehicles**

| Vehicle Type | Density (kg / gal) | | Emission Factors (g / kg fuel) | | | |
|---|---|---|---|---|---|---|
| | | | $N_2O$ | | $CH_4$ | |
| | Diesel | Gasoline | Diesel | Gasoline | Diesel | Gasoline |
| **Non-Highway** | 3.1920 | 2.8009 | 0.0800 | 0.0800 | 0.1800 | 0.1800 |

Source: Density values from EPA 2004. Emission factors from IPCC 1997.

**Table B-6: Vehicle Type Distribution Measured in Utah National Parks**

| Vehicle Type | Distribution |
|---|---|
| LDGV | 70.1% |
| LDGT1 | 13.7% |
| LDGT2 | 10.6% |
| HDGV | 0.8% |
| LDDV | 0.0% |
| LDDT | 0.3% |
| HDDV | 1.6% |
| MC | 2.8% |
| **Total** | **99.9%** |

Source: CE-CERT 2003a. Table 5.3.

**Table B-7: National Parks Study Vehicle Age Distribution used for Visitor Vehicles**

| Vehicle Model Year | LDV | LDT | HDGV | HDDV | MC |
|---|---|---|---|---|---|
| | | | | | |
| 2001 | 15.8% | 16.1% | 16.6% | 16.6% | 10.0% |
| 2000 | 15.8% | 16.1% | 16.6% | 16.6% | 10.0% |
| 1999 | 15.8% | 16.1% | 16.6% | 16.6% | 10.0% |
| 1998 | 15.8% | 16.1% | 16.6% | 16.6% | 10.0% |
| 1997 | 5.9% | 4.3% | 6.8% | 6.8% | 10.0% |
| 1996 | 5.9% | 4.3% | 6.8% | 6.8% | 10.0% |
| 1995 | 5.9% | 4.3% | 6.8% | 6.8% | 10.0% |
| 1994 | 5.9% | 4.3% | 6.8% | 6.8% | 10.0% |
| 1993 | 2.5% | 2.5% | 2.1% | 2.1% | 5.0% |
| 1992 | 2.5% | 2.5% | 2.1% | 2.1% | 5.0% |
| 1991 | 2.5% | 2.5% | 2.1% | 2.1% | 5.0% |
| 1990 | 1.0% | 1.8% | 0.1% | 0.1% | 5.0% |
| 1989 | 1.0% | 1.8% | 0.0% | 0.0% | 0.0% |
| 1988 | 1.0% | 1.8% | 0.0% | 0.0% | 0.0% |
| 1987 | 0.4% | 1.0% | 0.0% | 0.0% | 0.0% |
| 1986 | 0.4% | 1.0% | 0.0% | 0.0% | 0.0% |
| 1985 | 0.4% | 1.0% | 0.0% | 0.0% | 0.0% |
| 1984 | 0.4% | 1.0% | 0.0% | 0.0% | 0.0% |
| 1983 | 0.4% | 0.4% | 0.0% | 0.0% | 0.0% |
| 1982 | 0.2% | 0.4% | 0.0% | 0.0% | 0.0% |
| 1981 | 0.2% | 0.4% | 0.0% | 0.0% | 0.0% |
| 1980 | 0.2% | 0.1% | 0.0% | 0.0% | 0.0% |
| 1979 | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% |
| 1978 | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% |
| 1977 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** |

Source: CE-CERT 2003b. Mobile Inputs Received from Aaron Worstell by email, 2/11/03.
Note: This age distribution is revised slightly from that provided in CE-CERT 2003a.

# APPENDIX C: WASTE DISPOSAL BACKGROUND TABLES

This appendix provides further background information on the activity data and emission factors used to estimate GHG emissions from waste disposal for Zion.

**Table C-1: MSW Disposal Statistics for Park and Concessionaires in 2002**

| Park Operation/Source | Destination Landfill | 2002 MSW Disposed (short tons) |
|---|---|---|
| **Municipal Solid Waste** | | |
| Zion National Park | Washington Co. LF, Washington, Utah | 257 |
| Xanterra | Washington Co. LF, Washington, Utah | 147 |
| **TOTAL** | | **404** |

Source: Starling 2004; Louie 2004; Stewart 2004.

**Table C-2: Destination Landfill Characteristics**

| Landfill | Waste-In-Place (short tons) | Year Landfill Opened | Landfill Gas Captured per Year (standard cubic feet) | Annual Emissions Reduction from Flare | Annual $CH_4$ Generated (short tons) |
|---|---|---|---|---|---|
| Washington Co. LF | 1,292,000 | 1978 | 0 | 0 | 4,810 |

Source: EPA 2003a.

**Table C-3: $CH_4$ Generation Equation for Large, Arid Landfills**

| | |
|---|---|
| Large, Arid | 3,218 tons $CH_4$ + (0.001232 tons $CH_4$/ton WIP x tons WIP) |

Note: WIP = Waste-in-Place
Source: EPA 2003b.

# APPENDIX D: FORESTRY BACKGROUND TABLES

This appendix provides further background information on the activity data and factors used in the estimation of GHGs emitted from and stored in Zion's forests.

**Table D-1: Zion Forest Types by Area**

| Forest Type | Area (acres) | Area (ha) |
|---|---|---|
| Fir-Spruce-Douglas Fir | 4,570 | 1,849 |
| Ponderosa Pine | 30,084 | 12,175 |
| Hardwoods[a] | 39,174 | 15,853 |
| Pinyon-Juniper | 43,806 | 17,728 |
| Other Forest Types | 5,063 | 2,049 |
| Non-stocked Forest | 25,334 | 10,252 |
| **Total** | **148,031** | **59,906** |

Source: Bradybaugh, et al. 2004.
[a] Includes mountain brush forest types.

**Table D-2: Regional Factors Used in Carbon Stock Estimations**

| Forest Type | Average Tree C Density (MTCE/ha) | Average Soil Organic C Density (MTCE/ha) | Average Forest Floor C Density (MTCE/ha) | Ratio of Understory C to Live Tree C (%) | Ratio of Down Dead Wood C to Live Tree C (%) |
|---|---|---|---|---|---|
| Ponderosa pine | 66.3 | 70.4 | 20.3 | 4.1 | 21.6 |
| Fir-spruce | 113 | 137.5 | 37.4 | 2.2 | 17.4 |
| Hardwoods | 89 | 79.5 | 9.9 | 9.2 | 26.7 |
| Other forest types | 55.4 | 90.1 | 28.2 | 10.7 | 3.3 |
| Pinyon-juniper | 20.8 | 56.3 | 21.1 | 9.8 | 3.9 |

Source: EPA 2003. Densities are from Table O-1 for the Western US. Ratios are from Table O-2 for the Southern Rocky Mountain region.

**Table D-3: Area of Zion's Forests Burned in 2002**

| Project Name | Forest Type | Area Burned (acres) | Treatment Type |
|---|---|---|---|
| Lady Church | Mountain brush | 17 | Wildland fire |
| Clear Trap Piles | Ponderosa Pine | 36 | Mechanical (pile burn) |
| Blue Creek Piles | Fir-spruce-Douglas fir | 1 | Mechanical (pile burn) |
| Blue Creek | Fir-spruce-Douglas fir | 500 | Prescribed fire |
| Weeping Rock | Other - grass | 1 | Prescribed fire |

Source: Bradybaugh et al. 2004.

**Table D-4: Biomass Density Factors Used to Calculate Emissions from Forest Fires**

| Forest Type | Biomass Density (kg d.m./ha) |
|---|---|
| Mountain brush | 17,500[a] |
| Ponderosa Pine | 66,300 |
| Fire-spruce-Douglas fir | 111,900[b] |

Source: EPA 2003.
[a] The carbon density for chaparral was used for the mountain brush fires, as the two types of land cover contain comparable carbon stores.
[b] The average of the carbon densities for fir-spruce and Douglas fir was used for the Fir-spruce-Douglas fir fires.

**Table D-5: Emission Factors used to Calculate Emissions from Forest Fires**

| Gas | Forest Fire Emission Factor (g/kg d.m. combusted) | GWP |
|---|---|---|
| $CO_2$ | 1,531 | 1 |
| $CH_4$ | 7.1 | 21 |
| $N_2O$ | 0.11 | 310 |

Source: IPCC 2003.

**Table D-6: Data Entered into the FOFEM Model to Calculate $CO_2$ and $CH_4$ from Forest Fires**

| Project Name | | Lady Church | Clear Trap Piles | Blue Creek Piles | Blue Creek |
|---|---|---|---|---|---|
| **Forest Type** | | Mountain brush | Ponderosa pine | Fir-spruce-Douglas fir | Fir-spruce-Douglas fir |
| **Area Burned (acres)** | | 17 | 36 | 1 | 500 |
| **Region** | | Interior West | Interior West | Interior West | Interior West |
| **Cover Type** | | NVCS - *Andropogon gerardii* - (*Sorghastrum nutans*) Herbland | NVCS - *Pinus ponderosa* Forest | SAF/SRM - SAF 210 - Interior Douglas-fir - ex. From Habeck, '76 | SAF/SRM - SAF 210 - Interior Douglas-fir - ex. From Habeck, '76 |
| **Season** | | Spring | Winter | Winter | Spring |
| **Conditions** | | Moderate | Wet | Wet | Moderate |
| **Fuel Type** | | Natural | Pile | Pile | Natural |
| **Fuels:** | **Litter** | 0 | 0 | 2.6[a] | 1.2 |
| | **0 - ¼ in** | 0 | 0 | 2.83[a] | 0.3 |
| | **¼ - 1 in** | 0 | 0 | 5.42[a] | 0.4 |
| | **1 - 3 in** | 0 | 0 | 9.44[a] | 0.6 |
| | **3+ in** | 1.94 | 2.21 | 23.92[a] | 0 |
| | **Duff** | 7.24 | 9.46 | 38.73[a] | 25.7 |
| | **Herb** | 0 | 0 | 0.18[a] | 0 |
| | **Shrub** | 2.77 | 0.16 | 0.13[a] | 0.07 |
| | **Foliage** | 0 | 5.04 | 0[a] | 2.97 |
| | **Branch** | 0 | 0.64 | 0[a] | 3.88 |
| **Log Rotten %** | | 10 | 10 | 10[a] | 10 |
| **Duff Depth (in)** | | 1.2 | 1.1 | 1.8 | 1.8 |
| **Crown Burn %** | | 5.5 | 16.3 | 0[a] | 0[3] |
| **Moisture %** | **¼ - 1 in** | 15 | 15 | 22[a] | 9 |
| | **3+ in** | 15 | 15 | 40[a] | 9 |
| | **Duff** | 15 | 15 | 130[a] | 10[b] |
| **Log Loading Distribution** | | Even, Entire[a] | Even, Entire[a] | Even, Entire[a] | Even, Entire[a] |

Source: Bradybaugh, et al. 2004.

[a] For data that were not provided by Zion, default values from the FOFEM model were used.

[b] The minimum duff moisture allowed for the model is 10 percent.

**Table D-7: Area of Zion's Forests Thinned in 2002**

| Project Name | Forest Type | Area Thinned (acres) | Treatment Type |
|---|---|---|---|
| Oak Creek | Mountain brush | 38 | Thinning |

Source: Bradybaugh, et al. 2004.